

CHILDREN'S

TOYS

AND

WHAT THEY TEACH



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From The Times of December 14th, 1877.

“Science in the Nursery, or Children’s Toys and what they teach” is written, as the introduction states, on the principle of drawing out from the most familiar objects the topics of interest which they afford. There are, it observes, many different ways of looking at every object, and what any given subject is to us depends mostly on the point of view from which we regard it, and the sort of eyes which are engaged in its inspection. On applying this principle to the contents of a toy-shop, it will be found that the mechanism and action of the simplest toys connect themselves with important questions in science. This book is written on the plan of drawing out the elementary lessons of general knowledge which even children’s toys can teach. It treats in this way of the zoetrope and some other optical toys; dolls, tumblers, and other balancing toys; flying tops, shuttlecocks, arrows, bowls, sails and squirts and pumps, and cartesian divers; spinning dolls, peashooters, balls, the kaleidoscope, tops, kites, bats, and hoops; and there is added as a conclusion “a glance at a soap-bubble.” The style of the little work is just such as a highly-educated man whom his children persuaded to talk to them about their toys would be likely to use in discoursing to them on the objects of their amusement. We see in every page how, in the hands of a man of intellect, anything, however familiar, can be made interesting; some new light is thrown upon it, some curious piece of historical information as to its origin; or it is made to illustrate some grand law of nature or some discovery of science; and all is enhanced by grave touches of humour.

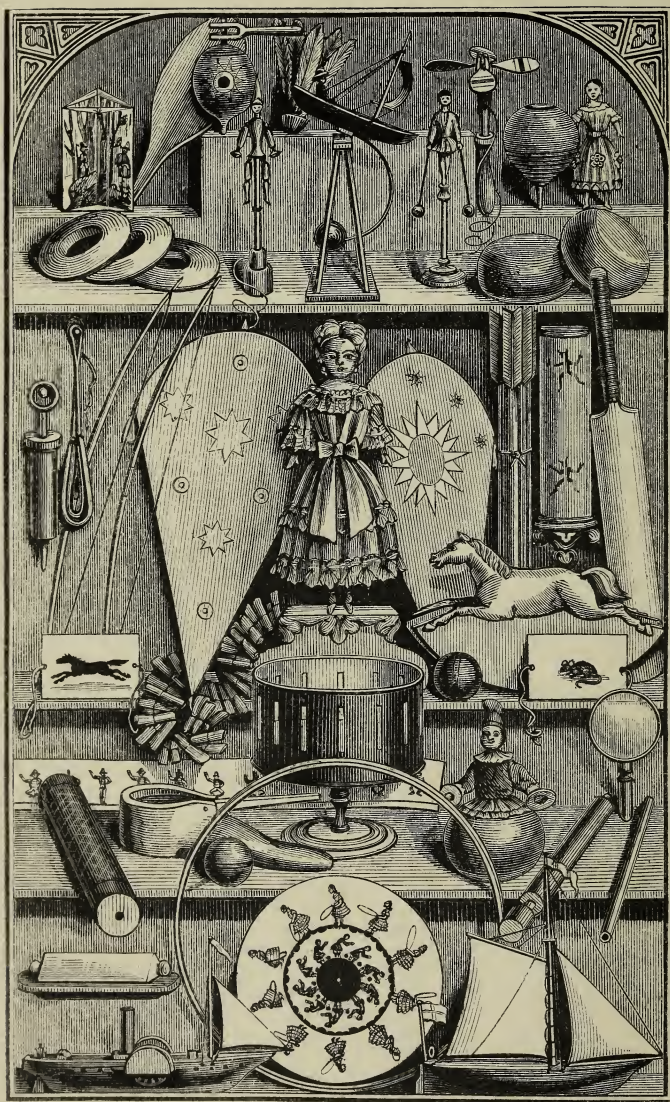


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*AND SOME ELEMENTARY LESSONS
IN GENERAL KNOWLEDGE
WHICH THEY TEACH.*

WITH ILLUSTRATIONS.

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CHILDREN'S TOYS.

INTRODUCTION.

“Sunt hæc trita quidem, Zoile, sed mea sunt.”

MARTIAL.

THE purpose with which the following pages were written, and that also with which they are published, should be stated, since much both of the language which is used and of the matter which is introduced would, without explanation, appear to be inappropriate. The Author, having been desired to give a lecture to a rural audience, chose for his subject “Children’s Toys,” partly because the theme in many respects promised well, commending itself as dealing with pleasant and familiar objects, and partly because it afforded a thread on which many topics of interest might be strung. It also seemed to be one upon which a busy man, having no leisure beyond such moments as he could snatch from an occupation followed amidst the din and distractions of a public place of business, might contrive

to put together something or other "out of his own head," as children say, which might possibly serve to entertain villagers, reference to books not being, of course, practicable under the circumstances. It was thus unavoidable that the material of the proposed lecture should be drawn only from such modest stores of rudimentary general information as the author might happen to possess. The merit, which in the present case may be a doubtful one, of originality thus belongs to the present essay, composed as it was under such conditions as have been mentioned. If, therefore, anything whatever should be found by the reader to have been borrowed from elsewhere, this occurrence must be due to the undetected personation of original thought by an accidental and unrecognised waif of memory.

The plan on which the present writer addressed himself to the task imposed upon him was not such, possibly, as is usually adopted, but which he desires to submit to the consideration of other people who may be called upon for a service like that demanded from himself, since it may be found, perhaps, to be not altogether a bad one. The plan in question was that of collecting whatever points of instruction or interest occurred to mind as being in legitimate connection (not limiting the claim to this relationship too strictly in deserving cases) with the theme to be discussed, and then putting these into something of bodily shape, and methodical array, by a written paper having the form of a lecture, but expressly intended to serve no farther purpose than that of fixing the several matters, and their sequence, on memory, so that

they could be recalled without effort. So far from any attempt being made, or desired to be made, to put even a single thought or statement into any such fixed terms as might be afterwards used to convey it in oral delivery, it was held that as a broad general rule which was applicable with exceptional force and strictness to such a case as that which was in hand, the most disastrous course which can be pursued with reference to a popular lecture, (as to most addresses of all kinds,) is that its exact words should be premeditated. Recited language, whether the fact that it is cut and dry, and not fresh, be discernible or not, may be faultless in itself, but has rarely the life and effectiveness which belong to the rough and ready inspiration of the moment.

It frequently happens that a petition comes from a clergyman entombed, perhaps, in some remote, dank, and joyless hamlet in the Fens, or immured in one of the woody and secluded fastnesses of the Weald, to an old College friend whose lot is cast in livelier scenes, begging him, if possible, for old acquaintance' sake, to come and "give an evening" at the tiny Reading Room of the Parish, and stir the stagnant atmosphere of the local mind with a few fresh ideas, and the sound of an unfamiliar voice. Such a request, apart from any regard to the quarter whence it comes, will be indulgently entertained in spite of personal inconvenience by any one who knows the generosity of kindness with which people in country districts ignore all shortcomings, and accord, like true gentlefolks, a cordial recognition to any effort honestly made, however feeble and barren it may be, to lighten for them

though but for a moment the leaden monotony of their lives. The following pages are published in the hope, which is, however, but very diffidently indulged, that they may afford some aid or suggestions towards a lecture on a subject of which, in good hands, much might be made, and which also possesses the advantage of being easily illustrated by objects which are cheap, and nowhere far to seek.



CHAPTER I.

I will suppose ourselves, if you please, in a toy-shop. Now pray do not credit, or, more properly speaking, discredit me with such impertinence as that of inviting you to bestow attention on things which, although, no doubt, they belong to the children's domain, are frivolous or puerile. You will remember that there are a thousand different ways of looking at every object, according to the particular standpoint for contemplation which the spectator takes up with reference to it, and that what any given subject is to us depends mostly on the point of view from which we regard it, and the sort of eyes which are engaged in its inspection. This reflection has not the merit of novelty, since it is borrowed from Lucretius, a poet and philosopher who lived about 2000 years ago.

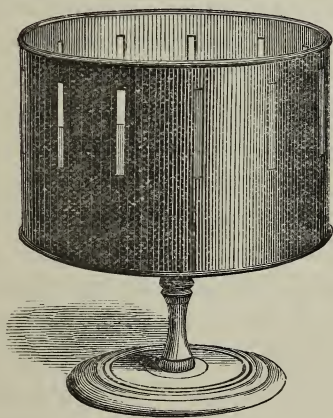
Now on applying this principle to the survey of the contents of a toyshop, it will be found that the mechanism and action of the simplest toys connects itself with important questions in science. Before we part company you will have plenty of opportunities for judging whether this statement is exaggerated or not. Some

years ago a clever book was written and published by some Cambridge men, partly containing translations into Greek and Latin verse of old English nursery rhymes. My plan for this evening is to attempt to do something which may be described as the converse of the task to which the authors of the "*Arundines Cami*" addressed themselves. They transferred the poetry of the nursery into language in which it could not be understood except by classical scholars. Now toys speak a language of their own which is Greek to the ignorant, and requires construing into simple English, but which, when it is thus rendered intelligible, is found to be rich in instruction, and to teem with suggestiveness.

A complete account of what toys are, how they are born into the world from the manufacturer's hands, and what is the nature and significance of all the various actions which they are capable of exhibiting, could not be given within the fraction of an evening which is allotted to a lecture. The discussion would fill a series, not merely of English winter evenings, but of nights as protracted as those which occur in the moon, where, as you probably know, each alternate spell of light and darkness lasts a fortnight. An Arctic night, indeed, of several months' duration might not allow us to get through the subject. We will therefore confine ourselves to a glance at toys in some few of their scientific aspects only, since these are of much more real and substantial interest than descriptions of the processes of manufacture. Themes of this latter kind are better adapted for supplying what is called "padding" to popular magazines, that is to say, for

furnishing forth the literary matter of a mediocre, or neutral, quality which is wanted for intermixing with the better articles which are alone worth something, so as to swell the bulk of the whole publication to a size which may appear to justify its price.

Which toy shall we look at first? Suppose we proceed on the established principle of "seniores priores", that is to say, give precedence to age, and begin with the zoetrope. Our selection will be well justified, for the zoetrope, in its original and simplest form, is probably the oldest toy which is known. Some of you may feel an impulse to interrupt me here, and say that the zoetrope is one of the very youngest, instead of the



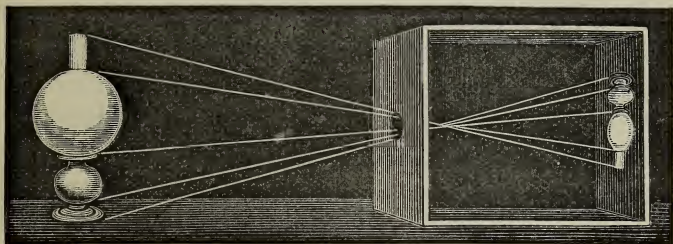
oldest, of toys, for that you recollect its being introduced to the world for the first time, as a novelty, only a few years ago. It is quite true that it was then brought out in a fresh form, as a new thing, but it had been already well known in other shapes, and

under other names, for any number of years. When I was a boy it was the "phenakistikope." The phenakistikope still survives at the Polytechnic in Regent Street, where it is called the "thaumatrope." There is, as we know, "nothing new under the sun," and toys, like fashions, come out again and again in resuscitated existences. The zoetrope is thus only an old friend with a new face.

You must understand me, if you please, to have been speaking of the principle on which the toy is founded, and which may be explained in the following manner. Suppose you have a ball attached to the end of a string, and that you whirl it round in the air, what is the appearance which is presented? The ball appears to form a ring. Or suppose that you take a stick with a red-hot end, and brandish it about, you can make with it long lines and curves of light of any pattern you please. Boys came into the world before toys, and you may be sure that displays of home-made fireworks of this humble order afforded a favourite pastime long before kites and rocking-horses were invented.

Now how is it that the semblance of a ring is created by a whirling ball, and a line of light by a single bright point when in rapid motion? The illusions in question are brought about by what is called the "persistence of vision." A real understanding of what is called the persistence of vision supplies a master key which will unlock the secret of all sorts of toys, and of all sorts of other things besides, so that it is desirable to make sure of its acquisition by taking with due care and patience the steps which are requisite for the purpose.

Now consider, if you please, the box which you have here before you to be a room, and imagine a bright sun, represented by this lamp, to be shining outside the window. The shutters are supposed to be



shut so that the room is dark. Bore at any spot in the side of the box where the shutters may be taken to be, a hole through which some rays of light can pass, and conceive these to fall, as they would naturally do, unless the sun were very high, on the wall opposite to the window. And lastly, fancy that a sheet, represented by this piece of paper, is hung up on that wall, just as if a magic lantern entertainment were about to take place.

Now here you have an exact counterpart, only on a larger scale, of an apparatus of which every person present has two examples in his or her own person—that is to say of the arrangements constituting the human eye. The hole in the shutters answers to the small black spot called the iris in the middle of the pupil through which light, bringing in itself the pictures of external objects, enters the eye. The sheet corresponds with a structure of very delicate and sensitive material, a sort of little curtain of exquisitely

fine texture, which is stretched at the back of the eye, and on which the images of objects towards which the sight is directed fall. This membrane is called the "retina". So that if you could look through the hole in each pupil of your friend's eyes while you are talking to him, you would behold a vivid, truthful, and perfect miniature portrait of yourself such as the hand of man would fail to accomplish, painted in duplicate on his two retinas, like images thrown from magic lanterns upon sheets, or the brilliant little scenes displayed by a camera obscura. The pictures would be, in truth and fact, coloured photographs.

We must not get upon the general subject of eyes just now because we have to do this evening with but one point only connected with them, and which, too, is solely concerned with the behaviour of the retina; but it may not be out of place to caution you against taking in too broad a sense what has been said of the dark room, the hole in the shutter, and the sheet, as collectively representing in a very general and rough manner the whole machinery of sight. Does any one suppose that we see with our eyes? We certainly do not. Our eyes (and by eyes I here mean the round balls which human beings and most other animals carry on the two sides of the bridges of their noses, or of their beaks, as the case may be,) correspond with the shutters, and are each pierced, like them, by a hole; while the retina plays the part of the sheet. Eyes, therefore, in real truth and fact, no more see than the perforated shutters and the sheet can be said to do so. What really does see is the brain. For from the back of each eye a nerve, called the optic nerve, goes up to

the brain and conveys to that organ in some inscrutable way impressions of the pictures thrown upon the retina. It is the brain, therefore, which sees, but *how* does it do so? Here we come on that mysterious borderland where matter and spirit meet. To the inquiry therefore "how do we see?" there is, in the present state of human knowledge, and probably will be for an indefinite time to come, but one reply, which may be given in Lord Dundreary's words: "It's a thing which no fellow can understand." Not sight alone, but all our senses, of course, present a similar enigma, which in every case is equally insoluble.

To return from these perplexing speculations to the one simple property of the eye with which the principle of the zoetrope is concerned, which is this. When a picture of any kind is thrown upon a sheet, it disappears the very instant that the light by which it is generated is turned aside or intercepted by a screen brought across its path, or as soon, of course, as the source whence it emanates is withdrawn. But when the miniature of an object is thrown upon the retina of an eye, then it does *not* vanish at the very same moment that the rays by which it has been painted are diverted or fail, but some little time, very short no doubt, but none the less a real and definite space of it, which is quite appreciable and can be measured, elapses before the impression which has been produced fades away.

The precise limit of duration of the survival of the image after the origin of the light which is necessary to sustain its existence has discontinued its supplies, or been shut off, depends on particular cir-

cumstances, such as, for example, the degree of force with which the impression has been made, which is greater, of course, in the case of a bright or clear object, and less in that of a dark or dim one, and the longer or shorter extent of time through which the process of engraving (for that, as will be explained presently, is the term which is the most accurately appropriate) has lasted. Each colour too, apart from its degree of brilliancy, whatever that may happen to be, has its own individual and characteristic rate of scoring its mark on the retina, red being the tardiest in such workmanship, and blue the most expeditious.

Moreover, an object or scene may be within range of view for too limited a period, or may be too faint, or too small, or through some combination of these or other incidents may exercise so transient or weak an action on the retina as not to make itself visible at all.

We are not, for example, conscious of the frequent intervals of pitch darkness which occur as often as we wink. A cannonball shot across your face would be too rapid in its passage to be visible. On the other hand, under certain particular conditions which may be arranged by an experimenter, a visual impression may be caused to last much longer than such images under ordinary circumstances do. But we will omit exceptional cases, and deal with such experiences only as are common and familiar.

Suppose, then, that a spark of fire which has depicted itself on the retina, is moved to a spot close alongside of that where it has been seen; and suppose that immediately afterwards it is again shifted to an adjoining position; and imagine this process to be

repeated a great many times, then the idea which the brain will acquire of what has been presented to view will be that of a continuous line of fire, because the earlier impressions made upon the eye will not have had time to die away before the later ones join on to them. A streak of lightning is merely an electrical spark travelling so rapidly that, as far as perception by human sight is concerned, it is at every point of its whole journey at the same time, thus qualifying in a certain sense the truth of the old saying that nothing can be in two places at once.

An explanation of this phenomenon which attends the faculty of seeing, and which is called the "persistence of vision," has been propounded by the theory, which in all probability gives a true account of the matter, that an actual scar, that is to say a local alteration of structure in the organism of the eye, is induced by the action of light at the spot upon which it falls, and where it brands, as it may almost literally be said to do, its mark. As in the case of other scars, it takes some time for the membrane which has been thus affected to re-establish the original arrangement of its particles, and thus obliterate the traces of the dislocation produced among them through the blow struck by light in its impact on the retina.

It should perhaps be stated that the blow thus inflicted on the retina is not a single one, but a sustained hailstorm, so to speak, of infinitely small strokes delivered in rapid succession. A ray of light is, in fact, mechanically speaking, a line of waves following one another in a file which issues continuously from the source of illumination. Light is thus a system of

undulations, and the several rays of which it consists (for, as you will hear presently, it is of a composite nature) are each of them tiny, but energetic, ripples. The size and the rapidity of motion of the wavelets which go to form these ripples varies with each colour. They can be measured and counted in each case, but it would not be relevant to our present purposes to describe the contrivances by which these appraisements are accomplished.

It may be mentioned that the continued presentment of objects to view beyond the moment at which they ought as it would seem, in the natural order of things, to disappear, is a phenomenon which is generated by other causes besides that of the persistence of vision. "Refraction" and "phosphorescence," subjects which we cannot now discuss, produce a like effect by means which may be just glanced at, and then dismissed. For example, it constantly happens through refraction that a body which has been shut off from direct view by an opaque shield set up between it and the spectator, as the setting sun is by the revolving Earth, continues to be seen round the corner, as it were, of the interposed screen, through the bending of the rays, as they pass from the object in question to the eye of the spectator, through some medium which is capable of diverting them from their naturally straight course. Phosphorescence is a property which all objects seem to possess in some slight degree, which is infinitely faint in most instances, but more pronounced in others, (as, notably, in the case of a petal of red geranium,) of continuing, after the light by which they have been illuminated is quenched or fails, to give out rays

of the same kind as those reflected by them up to the moment of that withdrawal.

Now let me turn abruptly to a different matter, but one which will be found to be quite apropos to the zoetrope. Suppose that you were asked, "What is the colour of things in general?" you would probably reply, "That is a question which it would take a lifetime to answer. Flowers exhibit an infinity of colours, and sometimes even a single object, such as a harlequin's coat, displays a considerable variety. Specify, therefore," you would say, "some one particular object as the subject of your inquiry, and we will tell you what its colour is."

I will do as you may be supposed to desire, and being at liberty to select anything which the world contains, will take for choice what is accepted as the highest ornament of the universe,—a lady's cheek. What is its colour? You will probably say, "A good specimen is of a delicate pearly white and pink." My rejoinder would be, "Yes, no doubt, that is the appearance which it presents when seen in Society, but what was meant to be asked was this (and please to observe the precise terms of the inquiry) — What is the original and native hue of a fair-complexioned young lady's cheek independent of any tints which it may borrow from the powder box or the rouge pot, or which it may steal from any foreign source whatever?" The answer to this question is "black as ink." Some young lady may here look aggrieved and incredulous, and exclaim, "You don't mean to tell me that my face, except for colours which are imparted to it by something or other which is no part of itself, or of myself,

is like that of a negress?" My rejoinder would have to be, "Pardon me, but the absolute requirements of truth forbid me to recede from the assertion which, however unacceptable to you, is one which it will be impossible to confute or qualify, that your face, apart from certain cosmetics with which Nature embellishes it, is jet black."

But to speak quite seriously, it is a truth which is now pretty well known to most people, that nothing in the world has any colour but light. Light, and light alone, supplies all the various hues which are known to us. When we find that a rose is pink, or a cabbage green, the real fact is that the texture of a rose is so constituted as to be capable of reflecting pink rays only, and that of a cabbage leaf green ones alone, both colours being supplied exclusively by light, without any contribution whatever from the plant itself, in either case. Neither rose nor cabbage is a source of colour in any larger sense than a looking-glass is the birthplace or origin of the faces which it mirrors. And since we only see any object, whatever it may be, by the rays which come from it to our eyes, the visual impression which we get in contemplating a rose is a pink one, and the image which we derive from the sight of a cabbage is of a green complexion.

The gorgeous hues with which chemists' bottles are resplendent are not, it is true, always and altogether reflected from the fluids inside those bottles, but still they are not a whit less than in the case of a rose or a cabbage extracted wholly and solely from light. The liquid in each bottle when it is seen by a lamp behind it acts as a sort of strainer, allowing the rays of some one particular colour only to traverse its substance. If the rays

which thus obtain free passage are blue, we see the fluid as blue ; if they are yellow the fluid is to our perceptions yellow, and so on with every colour. In the case of other substances, the particular rays which are dispatched from them to our eyes are not always filtered from the general stock which light contains in quite so simple a manner as that which has been described, but it is still always true, without any modification whatever, that colour is derived exclusively from the single source which has been mentioned. It has no independent existence of its own, but is invariably an extract from light, although the latter, until the usual association of its component hues is by some means severed, possesses no discernible colour of any kind.

Several questions might here be reasonably asked by those among you who are not familiar with these matters, or who have never thoroughly realised them in imagination, such, for example, as the following. If light is colourless until a portion of its rays is reflected from some opaque object such as a brick, or until it has made its way, with a loss of some of its elements, through some more or less transparent substance such as glass or jelly, why does the sun sometimes look red, as it is his custom to do in a fog? For he does not, like the moon, reflect rays, being himself the actual source of them, nor, obviously, is his light transmitted through his person to us from some spot or other in the heavens behind him, as if he were but the translucent face of an illuminated clock. The reason that his light is red under the condition of things which has been referred to is that in a particular state of the atmosphere the fog acts the part of a sort of colander,

and arrests all but the crimson rays, so that these alone succeed in reaching the Earth.

Again, the question might be asked why the sky is blue; for it seems difficult to perceive how any of the processes which have been hitherto described can be applicable to this case. The answer is that skyblue is the offspring, through reflection, of colourless light, but that it is generated in a manner which is far too complicated to be susceptible of convenient explanation here. The blue, however, comes wholly and solely from light. The atmosphere until, and only so long as, it is steeped in a blue extract of sunbeams is as black as night. As seen from the top of high mountains where the conditions by which the blue is evoked are sometimes wanting, the sky not unfrequently appears spread over the earth like a sable pall, presenting a weird aspect. An exemplification of the mechanical process from which the æthereal dye ensues may readily be presented, for by means of a common and simple little instrument, the polarising apparatus from a microscope, a richer and more glorious blue may be distilled from even a very small quantity of apparently colourless light than was ever displayed by an Italian sky.

Up to this point I have spoken only of the state of things in which some particular rays of a beam of light are disengaged from the bundle to which they belong by the object upon which they fall, and are transmitted, apart from their former companions, to our sight. There are two other contingencies which may happen to light. It may strike something which may have the property of forwarding it to our eyes in its unchanged integrity, or it may encounter one of the objects which

have the faculty of swallowing up and entombing it altogether, so that none of it is reflected. In the first case, that, namely, in which the whole of the light is reflected, the object whence it rebounds is white, and where it is totally absorbed, the surface into which it plunges is black.

The word "absorbed" has been used to signify the occurrence which takes place when rays of light falling on any surface disappear there, engulfed, as it were, and thus lost to sight. The term has been adopted as being that which is in common use, and which founds a claim to employment on "possession," which "is nine points of the law," of a place in all the text-books and treatises, whether elementary or advanced, which have been written upon the subject of light. By the rule of "Hobson's choice," therefore, it is forced upon our acceptance. It will serve its purpose well enough, provided that it is only taken to mean as much as this, and no more, namely, that rays which are said to be "absorbed" at any particular spot thereupon cease, as far as our calculations and perceptions are concerned, to have existence. The term must not be permitted to suggest the notion that the spot in question sucks in the rays by some species of action of its own, or that it is in any respect otherwise than completely passive with reference to them.

It may perhaps be as well, for the sake of precluding misunderstanding, to qualify, by a limitation which is almost self-evident, the statement made a moment or two ago in unreserved and general terms that an object which reflects all colours is white. It is only white when it gets all colours to reflect, because it cannot transmit

to the eye any hues with which it is not furnished for this purpose. It has no domestic factory of home-made rays whence any necessary ingredients of white light which may happen to be deficient can be supplied. A sheet of letter paper will be gray, yellow, green, or of any other colour which may happen to fall upon it; and in the dark it will not merely seem to be, but will, in actual reality, be black. The total absence of reflection comes, in its result, to the same thing whether it be due to want of light, or to the absorbent character of the surface on which rays fall, and is blackness in the one case just as much as in the other. Be it, therefore, well remembered that colour is simply the result and creature of a process, namely, that of reflection, and that it can thus last so long only as this is actually sustained, being altogether dependent upon it from instant to instant for its existence.

Colour, moreover, must thus necessarily vary with every circumstance by which the source of its being is, however transiently, affected. We call a sheet of paper white because it is convenient to speak of familiar objects as being of some particular distinctive hue which is conventionally attributed to them as their permanent property, and we assign to each the name of the tint which it wears under ordinary circumstances, just as it is said of a person usually ruddy that he or she has a florid complexion though the description may altogether fail to be applicable in moments of sea sickness or alarm. But no fixed colour is an integral part of the constitution and essential personality of any object, a whit more than the fortuitous disposition of clouds which may happen to prevail at this moment is a necessary feature

of the face of the sky, or our garments by day or night of ourselves.

What has been said as to colour being altogether the offspring of reflection is proved, when you come to think of it, by the fact that a highly polished surface, like that of a looking-glass, presents to the eye the objects which it mirrors clothed in the hues which they respectively wear at the moment, without the addition or the disclosure of any tint of its own. It might be added here, but this is a matter upon which we cannot now enter, that colours have not even so much existence as we have attributed to them, for that they reside in truth and fact in our perceptions, only, and have no substantive being of their own: in short, that they are altogether "subjective," as it is called, and not "objective."

You now discern the grounds on which it was stated that a feminine cheek, except for the colours which it obtains from sources extraneous to itself, is black. If it ceased to reflect, or, in other words, to borrow the whole of its tints from light, it would simply be of a jet-black. "Jet-black," indeed, would be too favourable a description of it. For jet, like other coal, has a gleaminess, or whatever it may be called, of its own, arising from a certain sort and degree of reflection which takes place from its hard and polished surface, and which imparts to it the brilliancy which renders it suitable for ornaments. An object which did not reflect at all would be of a deep, dull, and repulsive black, like an old hearse with all the nap worn from its cloth, and the varnish from its panels. A black silk hat reflects a little, in the same manner as jet, which relieves

the general darkness of its effect. A felt hat of the same colour appropriates, without making any corresponding return, nearly all the light which reaches it, and it has consequently a more heavy and dead appearance.

The account which has been given of the origin of ladies' and other people's complexions holds good for all circumstances and times, and in every detail. If the tip of a human nose gets blue with cold on a frosty day, or if the proprietor of that nose, on lapsing into the plight of a desolate old bachelor, or old maid, is led to seek comfort in the brandy bottle, and thereupon the feature which has been mentioned comes by degrees to a fiery red, like a wild poppy, both the phenomena of colouring which have been specified are due to changes in the circulation of the blood at the spot in question, which influence the reflecting properties of the skin at that particular point. If, at this moment, we were to put out the candles, and play snap-dragon with raisins and lighted brandy, the most rosy complexion in the room would become, as you know, as slaty and cadaverous as that of a ghost with a sick-headache, because the light which comes from the flame of burning brandy supplies no pink flesh-tints for the human skin to reflect.

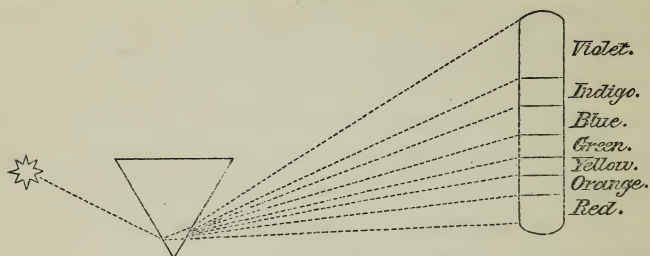
The old trick which books of what is called "parlour magic" describe of robbing a picture of all its colours and thus causing it to appear to be a print, is accomplished by illuminating it by the flame of salt, which furnishes nothing but yellow light, so that the surfaces of the various pigments on the canvas cannot, severally, obtain the particular rays which alone it is in

their nature, and within their capacity, to reflect. A red geranium, if it were to be seen by the light of a snap-dragon, would not only appear to be, but would be, in the strict and proper meaning of correct language, really yellow, for the time being, although it would still be right to call it by the name under which it is usually known, as indicating the particular species of plant which it is, and correctly describing the decided characteristic by which its flowers, under ordinary circumstances, are marked.

But how do we know that light, which, to all appearance, is wholly devoid of any colour, contains within itself, literally speaking, all the hues of the rainbow? Sir Isaac Newton was the first person to point out that this is so, and he showed how to prove it. Can we, then, take a beam of light to pieces, as we might a piece of coloured mosaic, or a child's dissecting map, and display the various ingredients which enter into its composition? Nothing is easier. We can, by a simple method, break it up, and show it in all its colours at once, which, when mixed on Nature's palette, supply every hue which we see about us, or which is anywhere to be found. By adopting a process of another kind we can display these colours, and the diversified combinations which they are capable of forming with one another, in an absolutely endless series. Anybody who works with a microscope has often to dissect light in both these ways, but far more frequently in the latter, as a necessary part of his regular business.

Here is a common toy, claiming our notice in that character, and which is, as you see, a mere plain three-

sided piece of glass, something like a wedge, or a row of wedges joined at their sides. It is called a "prism."



This plaything, simple as it is, is a most effective instrument for dissecting light, and is a counterpart of the identical tool which Newton used for the purpose. Any one can repeat in an ordinary room, and with great ease, the interesting and beautiful experiment by which Newton's grand discovery as to the compound nature of light was reached. Such a prism as this forms the whole apparatus which is required, and costs about sixpence, but it is not necessary to spend even a penny, for it is very easy to borrow (or even to steal, for so good a



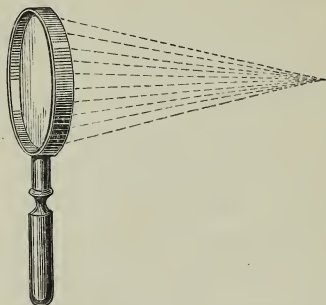
purpose, would be an act of very mitigated turpitude) a three-sided glass drop from a chandelier, or from one of the common lustres which are to be found on a drawing-room chimney-piece. Such a drop will be a tolerably good prism, and will behave as such; and the most elementary book on Science, or indeed many of the books on amusements for children, such as "The Boy's Own Book," will be found to give full directions as to how the instrument is to be adjusted for the performance of its duties.

It is not expedient to show you the process here, and now, in actual operation, because it could not be satisfactorily displayed to a numerous body of spectators, unless it were done on a large scale, and with a profusion of light, so as to exhibit the colours with due brilliancy. But to accomplish this it would be necessary to darken the room, which would be inconvenient, and take time. Besides which, whenever it next happens that the sun shines through a shower of rain, nature will supply an admirable working diagram illustrative of what has been said, in the shape of a rainbow. The falling drops will under such circumstances have by their combined action the effect of a prism, and will unravel the strands, as they may be called, of white light which come from the sun into the separate skeins of coloured rays from which they are woven.

Do not make the mistake of imagining that when a beam of light which is apparently pale is caused to pass through a prism, and reappears on the other side in a glorified form as a brilliant array of hues, the glass adds anything of its own in the way of colour. One toy illustrates another, and the present is a favourable opportunity for noticing a common and favourite old plaything, to wit, a burning-glass, because this latter will show that there is not the slightest ground for fancying that the prism has necessarily anything to do with the colours in the sense of being itself the parent of any of them.

Here is a burning-glass. You recognise it by its familiar shape, which is that of a circular disc, fat in the middle and thin round the edge, like a solid wheel with a very thick nave. You know that when you so

hold this glass as to receive the warm rays of the sun on one of its faces they meet in a bright point at a certain distance on the other side. The action of the glass



upon the rays is to make them converge, that is to say to slope towards one another, till at last they all assemble at the same spot. And you must have found that if your finger, or anything else, be placed at the brilliant speck where the rays meet, it will be burnt. The point in question is, as you know, called the focus, and you will discern the propriety of this name for it when you learn that “focus” is the Latin for “fire-place.”

Any substance, or combination of substances, which possesses the faculty of permitting the free passage of the sun's rays, and of so influencing the directions of their courses as to cause them to meet at a focus, will act with more or less complete effect as a burning-glass. A decanter of water was one day standing on my study table when the sun, although the month was October, was shining into the room rather warmly. The bottle, when full of clear water, formed, in effect, a solid and transparent globe. It happened also to be precisely

of the right construction to act well as a burning-glass, since its surface was quite plain and smooth so that it did not scatter irregularly the rays of light or heat passing through it as it would have done if it had been moulded or tattooed with a pattern, as most decanters are. The sun's rays, falling on it as they did on the occasion in question, were brought by the globe of water, as though by a burning-glass, to a focus, and this happening to come precisely at the surface of the table-cloth, burnt a hole there.

A clear piece of ice, if cut to the form of a burning-glass, would comport itself as such, and you might set on fire anything capable of burning by rays collected and brought to a focus by its means. The experiment has often been shown. You are not likely to imagine that the ice would add much heat of its own to that of the rays passing through it. Nor can the bottle of cold water which was mentioned just now, have contributed anything on its own account to the fire which scorched the table-cloth. Similarly, the action of a prism is to alter, in different degrees, the courses of the several rays which pass through it, and which constitute, as long as they are united, colourless light. It causes each of them to part company from the rest, and to disclose itself in its own separate individuality as a streak of some particular hue standing confessed as though at the touch of Ithuriel's spear, but it supplies no new tints of its own, nor does it to the slightest extent intensify those which it thus compels to reveal themselves.

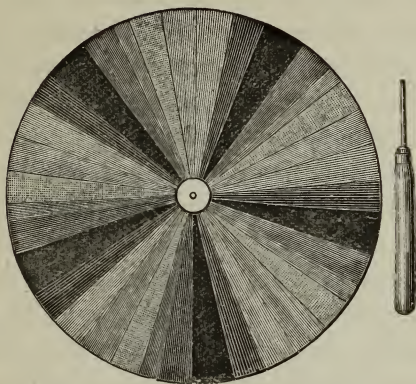
Having dealt with a ray of light after the fashion with which paupers in workhouses have to treat pieces

of old rope by picking them to pieces for oakum, can we put it together again? Readily. One method of so doing is by arranging a second prism in such a situation and attitude as that the rays which have been divorced by the first one shall be remarried, that is to say, again blended, by this other. But there is a plan whereby the rays may be, in effect, reunited, which is founded on a principle of an altogether different kind. It forms the point towards which I have been leading you for some time past, and which I wished you to reach fully equipped with preliminary information so as to understand it fully, since it exhibits the principle of the zoetrope in a very clear and interesting manner.

You were told just now that when an object reflects all the colours of the rainbow it appears to our eyes as white. You also learnt that when we see anything which is afterwards withdrawn from sight, it still, to our perceptions, remains for a very short time at the place where we originally beheld it, because the visual impression made by it upon the retina of the eye takes some little time (which averages about one-eighth of a second) to fade away. From these circumstances it follows that if we could bring all the separate colours of which a ray of light is composed, in sufficiently rapid succession, to one spot, we should, in effect, see them all together, and thus get a perception of white as the general result. This "chromatic," that is to say, variegated, disc, forms a device for accomplishing this experiment, and it will prove what has been told you about the composition of white light, and the persistence of vision, to be true.

We have here, as you observe, all the colours of the

rainbow disposed in their proper order in triangular, or wedge-shaped, areas, or what are called sectors of a



circle, following one another in the same sequence which Nature herself observes when arranging them in the sky. They are repeated in similar groups all round the disc. Now consider any point you please upon the disc, such, for example, as this one at the top. The colour which happens to be there at this moment is orange. If the disc be spun very rapidly, all the other colours will come in their turn, in quick succession, to the same point, and before the impression which any one of them makes upon the eye of the spectator has faded away, each of the others will have scored its own mark at the same spot. The spectator, therefore, will in the result see at this point all colours, that is to say, white. What is true for any one point in the disc is, of course, by a like process of reasoning, no less true for any and all others which might be taken on the same surface, so that the whole presentment to the eye is white.

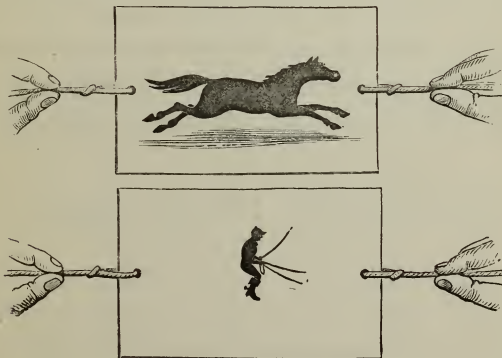
The disc might just as well, as far as the purpose for which it has been used is concerned, have been painted with fewer stripes of colour than are actually employed ; with any number, in fact, not less than two. For since all the colours of the rainbow, taken together, make white, it is plain that if you combine, say, half of them in one mixture, and the other half in a second, in the proper proportions, of course, in each case these two groups, when united, will assume the hue of which they are the ingredients, whenever they are amalgamated to the eye by sufficiently rapid motion. Any two colours, thus, by their combination, producing white, are said to be “complementary” to one another.

That the blending of the colours is really and altogether due to the cause which has been stated is proved by the fact that if the disc, when spun as before, be made visible for so short a time only as that no motion which is sufficiently large to become appreciable by our senses takes place within it, the colours all appear separate, just as if the whole apparatus were at rest. To all intents and purposes it is so, as far as the spectator is concerned. If the disc be illumined brightly, but only for some infinitesimal portion of an instant, as, for example, by means of the electric spark, which gives a flash of a duration of less than the four-thousandth part of a second, no motion, nor any consequence of motion in the shape of fusion of hues, is perceptible. Similarly, if a man galloping at night on a fleet horse were to be revealed, for a moment only, by a flash of lightning, he would appear to be standing stock still.

Any one desiring to pursue this subject further

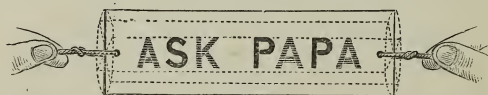
should make inquiries as to certain cogged wheels devised by Faraday illustrating the effects of persistence of vision, and exhibiting a multiplicity of very curious optical phenomena. The only apparatus required will be such as anybody can make, and it will cost absolutely nothing.

Here is another toy depending upon and illustrating that property of our eyesight with which we are now so familiar under the title of persistence of vision, and since the contrivance which is before us seems to occupy a position as a sort of halfway house between the chromatic disc and the zoetrope, it has a valid claim to be noticed at this moment. On one side of this card, as you see, is a horse, and on the other side a rider. By making the card spin rapidly, so as to present its two faces alternately in quick succession, the figure on one side combines in its effect to the eye with that on the other, and the general result is a complete picture of horse and rider.



This toy is capable of a very practical application to the serious exigencies of real life. For conceive an in-

cident of the following kind. Such things have occurred, are daily occurring, and will continue to occur till the end of time, so that you will not be called upon to exert any violent spasm of imagination in picturing to yourselves the scene which is to be conceived. Pretty young lady, unmarried, but with no intention to remain so. Eligible young gentleman, a warm admirer of the young lady, but perhaps bashful, perhaps irresolute; at any rate he does not come quite to the point of saying what he ought to say, and what the young lady desires that he should express in the shape of a formal and distinct proposition. After a long and somewhat embarrassing silence, young lady takes up, with seeming inadvertence, a card with two strings attached to it, and begins to twirl it. It is but a mere child's toy, quite innocent and unmeaning, since it has only a few letters, spelling apparently nothing, on its face. The letters are these S A A. When the card is spun, the coincidence is disclosed that it is inscribed with some other equally unmeaning letters on its back, namely A K P P. These latter, when the motion becomes rapid, combine, through the persistence of vision, with the other letters on the retina of the young gentleman's eye, and they

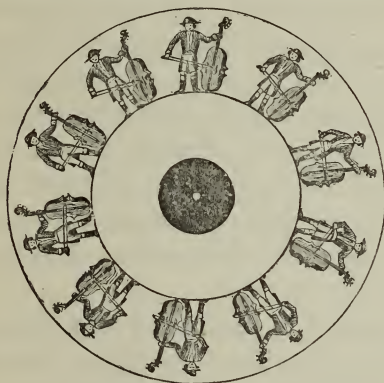


form together the words, "Ask papa." The two assemblages of letters, when thus conjoined, are fraught with obvious significance and suggestiveness.

And now to apply to the case of the zoetrope the general conclusions on various points which we have

reached by a course which was not in fact by any means so random and purposeless as it may have seemed to be.

In the zoetrope, a figure is painted at the end of a long strip of paper. It may portray anything you please, as, for example, a man playing a drum, with his arm in a certain position. Close to it on the same strip



is another picture of the same man, but with his arm moved from its original attitude a little in one direction.



Near the second picture is a third, which is again a similar one, except that it represents the arm in which a change of position has been already noticeable moved a little further still in the same direction as before. A similar set of pictures, alike in all respects, except that the particular variations of a single detail, or of certain details, which began with the earlier part of the series

are progressively increased along the line, is continued throughout the whole length of the strip.

The strip is now laid along the interior surface of the revolving cylinder (see woodcut p. 7) which possesses a contrivance for making the figures visible not all at once, but in succession, through loopholes suitably arranged for this purpose ; and the drummer thus comes in his different attitudes, one after the other, into view. As he does so each picture combines and blends in the eye of the spectator with that which has preceded it, and melts into the one which follows it. Thus the general effect of—say three—pictures is that of a drummer passing from one attitude through a second into a third in a very short space of time, so that he appears to be in motion.

It is necessary to apprehend fully the precise use of the slits through which the figures must be viewed. If, instead of peeping through them, you gaze into the zoetrope over the upper edge of the open cylinder when it is in motion, you only see an indistinct band of colour. This is owing to the figures on the strip being, to the eye, all fused together by their rapid motion, just as the tints on the chromatic disc were, by a like process which was explained to you just now, melted into one general white.

It is from a similar cause that when you travel in a quick train the hedges on each side of the railway turn into green torrents, because there are no intervals between the impressions which their component details make upon the sight. The eye is not indulged with even the smallest fraction of an instant's rest, and twigs, branches, and leaves, all, visually speaking, lash

the retina, one after the other, with such overwhelming rapidity that the optic nerve becomes perforce like a witness giving his evidence in so hurried and tumultuous a fashion that the judge who has to hear the cause, and whose office corresponds with that of the brain in the case under consideration, is unable to keep up with him, or write down what he says.

In the zoetrope a main object of the contrivance is that the succession of pictures shall be broken by short intervals, one of which is to be interposed between every two contiguous members of the series. The eye thus obtains such rests as are conceded to it during the periods through which the spaces between the several slits in the side of the zoetrope are passing before it, since these, as presenting no defined images for apprehension, are equivalent to blank tracts. If these spaces and intervals were long, the eye would possess itself of each figure unconnected with either of its neighbours, and no illusion whatever would arise. But the figures coming rapidly, one after the other, into view, the aggregate effect which is presented by them to the spectator is as follows : a figure, say, for example, that of a man with his arms hanging by his side, is first shown. Instantly, or, rather, much less than instantly afterwards, the eye gets the same general figure of the same man, in the same general attitude, but with one of his arms a little raised from his side. Again, less than instantly afterwards, the eye has presented to it the same figure of the man with whom it has already made acquaintance in an attitude which is, as a whole, unchanged, but with the arm which had been previously given as slightly raised from his side now lifted a little more

still. But this, you know, is the precise character of the spectacle, in all its exact details, which the eye would see if the man who is under observation were a real personage raising his arm.

The eye is thus imposed upon by a delusive facsimile of what happens in real life. It conceives itself to be beholding a well-known succession of appearances which is inseparably connected with, and is the invariable result of, a particular sort of motion of an object of a familiar kind with which it is fully conversant, and it naturally accepts this counterfeit presentment as conclusively indicating that such a motion as the one in question is actually taking place in that object. The eye is, in fact, doubly deceived. For suppose, for example, that the spectacle which it fancies itself to behold in the zoetrope is that of a child jumping up and down over a skipping-rope. It is not true that there is a figure doing anything whatever of this kind. The vertical, that is to say the direct up and down, motion of the figure which is viewed is altogether an illusion, but it has a horizontal, that is to say a sideways, movement as it turns round in the cylinder of the zoetrope which eludes detection by the eye, although it is fully known to be taking place, and is actually within the scope of close and direct observation.

The nature of the optical deception which occurs may be illustrated by an exactly converse case of error. The same eye which allows itself to be persuaded that a figure in the zoetrope is moving perpendicularly up and down, although in fact its only real change of position is at right angles to that which is attributed to it, will be no less ready to accept the visual imposture

which waves in a storm create when they seemingly roll towards the shore. You probably know that no waves of deep water ever do anything of the kind, but that they simply rise and fall vertically, that is to say over one and the same fixed spot, just as if they were glazed-calico billows at a theatre, where the outer margin of the boundless and raging ocean whence they spring is nailed to a wooden frame a few yards square.

The case is the same with the waves which may be shaken along a loose string, where also there can, of course, be no transference of particles along their line of undulation. If you go to the Brighton Aquarium, you will see the optical effect upon which we are dwelling exhibited by the conger eels. Their favourite position and attitude appears to be that of poisoning themselves with their noses in the cleft of a rock, and with their long bodies streaming out horizontally backwards. They constantly send little ripples of motion from their heads to their tails, such as those which run along a flag or handkerchief when floating forth upon a brisk wind. There cannot, of course, be any real transmission of the substance of the eels' persons from their gills to their latter ends.

You thus find that the eye is a credulous greenhorn of easy gullibility in respect of the facility with which it may be duped. It is so often mistaken about what it supposes itself to see, that hereafter if any one should asseverate some unlikely thing which you may not be prepared to accept as a fact, and should say, "Must I not believe my own eyes?" you, remembering the zoetrope, will be emboldened to reply, "Certainly not in all cases."

You will have remarked that the zoetrope shows twice over in its action that our eyes possess the faculty of what is called persistence of vision. For it is owing to persistence of vision that each figure coalesces more or less completely with those on either side of it, which, as we have seen, is the source of the appearance of motion which the trio, when acting in combination, present. It is also due to the same quality of eyesight that although the loopholes which are looked through are of very small width, yet the pictures are seen through them without any sensible interruption whatever, notwithstanding that there is a broad unperforated tract of metal between every one of them and its next neighbour on either side. Hence, as the zoetrope revolves, a screen interposes itself between the eye and the spectacle which is before it during the whole of the time which elapses from the departure of one of the slits from the front of the spectator's nose till the arrival of its next successor at the like situation. Were it not for the persistence of vision we should only see the picture intermittently, or, as it might be expressed, interjectionally.

You may have noticed that I have endeavoured to explain the effect of the loopholes twice or thrice over. This has been done not by any means inadvertently, or through any low estimate of your intelligence, but designedly, and for a reason which is by no means uncomplimentary to your understandings. The truth is that the matter in question is a very difficult one indeed to enter into and realize, and requires to be thought over both long and carefully before it can be thoroughly digested and assimilated by the mind.

It will be found to be inseparably connected with other subjects of interest, such, for example, as that of the combination of faculties which are essentially necessary to sight in any full sense of the term.

One of the first things which you were told this evening was that we do not in any real or complete manner see by our eyes. It is the brain which, arguing automatically from its own knowledge, and its stock of previous experiences, puts its own construction on the images which the eyes present to it. The brain, however, would be unceasingly misled if it were to suffer itself to be cajoled into accepting the pictures which are brought to it from the retina for correct delineations, as they stand, of the objects whose external characteristics they profess to represent. Nor do the pictures give the mutual relations of any set of objects to one another in point of size or position with the least approach to the real truth. They supply nothing more than the materials for founding some judgment on these points. We know that a man born blind, and thus without experience of how the evidence of the eyes should be translated into a veracious representation of fact, would, if he were to be suddenly gifted with sight, "see men as trees walking." The same person would naturally pronounce the sun, if he viewed it through an attic window, to be smaller than the pane of glass through which he beheld it, as, indeed, visually speaking it undoubtedly would be as far as he was concerned. In this latter case, the eye in taking the sun and window to be on the same plane, that is to say on the flat surface of the same picture, (which, leaving out of account the correction to be made by the mind, it must

certainly do,) would also make the trifling error of about ninety-five millions of miles or so in its estimate of the comparative distance from itself of the two objects.

Visions conjured up by the imagination are said to be seen "by the mind's eye." Conversely, real and substantial objects, before they can be "seen" in any practical sense, must be viewed, literally speaking, by the eye's mind. Our idea of motion, for example, is not, as Lord Brougham pointed out, a direct perception by sight, but is a deduction from a rapid and automatic process of reasoning founded on data supplied by vision. Similarly we judge of distance by size, and appraise bulk by distance: both are mental processes. We cannot dive farther into the depths of this topic here, but some acquaintance with it is indispensable to a full understanding of the zoetrope.

Let me take this opportunity of making the remark, which is exemplified by the zoetrope, that although toys are generally rough and simple enough because they answer their intended purposes far better by being thus cheaper, most of them are capable of taking improved and elaborated forms in which they may become valuable instruments of science, and mediums for the exhibition of beautiful and marvellous effects. The prism which we talked about just now, when employed as what is called a spectroscope, opens up to us a whole universe of knowledge of things in the heavens, and of things on earth, and indeed, it may be added, of things under the earth, since it has a special applicability to the examination of metals. The spinning cards which were shown to you may be made, by the

addition of some suitable tackle, vehicles for displaying many curious and intricate phenomena.

In concluding the subject of the zoetrope, let me offer a suggestion for some pictures of a novel kind which might be exhibited in it. Take a very young child; but anybody who is not very old will do. A child will be the best because the changes in early youth of any individual's personal appearance are more rapid and pronounced than in later years. Selecting, then, anyone you please, but a child for choice, photograph him or her at several regular intervals. It does not matter how long or short the intervals are, provided that they are frequent enough to prevent there being any very violent difference between the effect of any one given portrait and that which immediately succeeds it. Having obtained a series of such likenesses, arrange them in their proper order, according to their respective dates, along a strip of paper of a shape and size proper for use in the zoetrope. Put this into its place, and spin the apparatus in the usual way. The result must be that as each picture, still bearing traces (which are in fact graven on the spectator's eye) of its more immediate predecessors, dissolves into its nearer successors along the line of portraits, you will have, as in a moving panorama, the progress in life of the individual who is depicted.

If you turn the cylinder of the zoetrope in a direction opposite to that of the sequence of dates, you will get the curiosity of the seven ages of Shakespeare in their reverse order. If the series of likenesses be sufficiently numerous to illustrate every stage in the whole life of an old man, you may within the compass of a few

moments see him in his gray hair, or bald, as the case may be; and, as the instrument revolves backwards, and forces Time with unaccustomed footsteps to retrace his track, you will see a crop of hair springing up on the gentleman's head, and growing darker and darker till the period of the fullest bloom of youth, with its rich luxuriance of "thatch." After this you will notice that the locks become again lighter, and then lighter still, and scantier too, as the head whose annals are being pictorially unfolded comes back to the days of its early childhood, till at last it arrives at the very dawn of the first morning of its life, when the little infant's tiny "nut" which has now come into view resembles another sort of nut in respect of its bareness but is a good deal pinker and softer.

It is said that when a man is drowning it sometimes happens that by one of the marvellous strides which memory, at such moments only, acquires a capacity to take, all the circumstances and actions of his past existence flash upon his recollection in a single instant. We may get, you see, a vision of the same character brought actually to the corporeal as well as to the mental eye, through the means of a rapidly-moving series of photographs such as have been described, recalling the various successive phases of a man's bodily personality.

For example, suppose that at one instant a face which is under contemplation in the zoetrope betrays traces of strong excitement, degenerating into anxiety, then brightening up into rapture, afterwards shading down into mere joy, and eventually dissolving into qualified satisfaction. An old man looking at the countenance of his earlier days as it passes through these vicissitudes

of expression, might possibly be able to interpret the riddle of its alternating oscillations "from grave to gay, from lively to severe," in some such way as follows. "I recognize that aspect of excitement as the sort of mien which I must have worn when I fell in love: the anxiety which follows it betokens the suspense of courtship, before Fortune had pronounced whether the enterprise was to turn out prosperously or not. The succeeding rapture indicates acceptance. The joy which ensues proclaims the occasion when the announcement was conveyed to me that my house was now gifted with a son and heir. The transition of that joy into a display of less ardent satisfaction marks no doubt the ebbing of the springtide of delight which set in when I was made acquainted with the rather startling fact that in this instance the words "son and heir" had a richer significance than usual, and meant twins, or even a triplet, and when, by way of evidence that such was the meaning which belonged to the expression in the present case, they all began to scream together."

But without the protracted trouble which would be required for obtaining a succession of portraits of anybody at certain intervals, the same kind of experiment may be shown in many other ways. Take, for example, the bud of a flower, and have a fresh sketch of it made, either by a pencil or photography, every few days, or oftener, according to the greater or less rapidity with which it advances towards maturity. The bud may remain on its tree, or be put in water, if it will expand there. Insert the series of sketches thus obtained in a zoetrope, in the manner which has been already described, and on setting the toy in motion the appear-

ance presented to the eye will be that of the bud expanding into a full-blown flower, or, if the cylinder be turned the other way, the effect, of course, will be just the opposite, namely, that of the flower folding itself up, and retreating within the coat of its original bud.

One more illustration of a course of development, or of the reverse process, may be suggested. Select an egg whose inmate is just about to burst through the shell, and get a picture made of it; or you can start, if more convenient, at a rather later stage in the chick's life when it has escaped from confinement in the cramped premises wherein it was born, and stands forth proud and free as a soft little ball of yellow plush, not as yet endowed with the dignity of a tail, and supported on a pair of spindle shanks so thin that they are only discernible in very clear weather. Procure, as before, your chronological gallery of portraits of the chick, terminating with a cock or hen, as the case may be, arrayed in full plumage. You will now, with the aid of the zoetrope, be in a position to exhibit, within almost the compass of a single glance, the whole course of a fowl's existence from the "welcome little stranger" stage—the juncture when it escapes the liability to which, as long as it remains within its shell, it is exposed, of being poached, to the time when its immediate prospects become associated with bread-sauce. Now when you go home this evening, and your friends ask you about the lecture, you will be able to say (at least, so it is to be hoped) that you heard some things that were new to you; and if you are asked for an example, you can reply that the lecturer told you how to put back a full-grown barn-door fowl into an egg.

It may be mentioned, as a concluding observation upon the subject of persistence of vision, that were it not for this quality of our eyesight, a landscape, even when steadily gazed upon, would be but very imperfectly beheld. This point would take a little time to explain, as it is not a simple one, and I therefore remit it to the consideration of any of you who may have sufficient enterprise to investigate it for yourselves.



CHAPTER II.

WE have been walking up to this point on a somewhat rough and stony road, and some of you may perhaps be a little bit footsore, and require a short rest. In other words, we have been treading a path of inquiry which is not quite, perhaps, at every point of its course, the very smoothest which could be followed, so that you may like to turn for a time to something or other which has nothing to do with so stiff a science as that of optics. Suppose, therefore, that we take a doll into our hands, and see if it has anything to tell us. At first sight a doll might be imagined to be barren of interest for grown-up people, since it does not "work" as optical and mechanical toys do, but is, like most young ladies, an inanimate, mindless, though rather ornamental sort of object; a pink-and-white structure, fashioned after the semblance of a real human being. Yet there is a great deal which might be said about dolls, as will appear by the following anecdote, the truth of which is within my own personal knowledge.

When I was an undergraduate at Trinity College,

Cambridge, Lord Macaulay, the celebrated historian, who was a member of the College, and very much attached to the place, used frequently to come and dine in our Hall. Lord Macaulay teemed with knowledge of all sorts and kinds on all manner of subjects. He reeked with information from the crown of his head to the soles of his feet. He was also of a very lively disposition, and a prodigious talker. The result of the conjunction of these particular qualities was that, whatever subject of conversation might be started at the dinner table, he used to go off upon it "at score," without break or pause, his discourse being a monologue, since it afforded no chink or opening through which a single word could be edged in by anyone else. Lord Macaulay's self-abandonment to the impulses of his natural vivacity and fecundity of talk was like the gallop of a thoroughbred horse who takes the bit between his teeth and bounds along, deaf and insensible to everything but the promptings of his own impetuosity, till he has run himself clean out of breath. The Dons, as they are called, that is to say the tutors and authorities of the College, among whom Lord Macaulay sat, got tired of the perpetual wagging of his Lordship's tongue, so they formed a conspiracy for muzzling him through the manœuvre of choosing some theme for conversation on which it was impossible, as they confidently supposed, that he could find anything whatever to say. And the topic which they selected out of the whole universe of conceivable subjects, as being the one from which the most ingenious inventiveness could not possibly contrive to extract any material for discourse, was that of dolls. But they

had mistaken their man. For Macaulay was so brimful of thought and knowledge about dolls that it took the whole rest of the evening, from the time of the first mention of the word, to allow his flood of talk upon them to run itself off.

Now this anecdote is suggestive. It shows that if there is anyone among you who would like to write an essay on a popular subject, which would have all the charm of being new as a literary theme, and which would at the same time be susceptible of interesting and instructive treatment, a more promising and fertile text than that of dolls could hardly be chosen. I cannot address myself fully to the enigma which it presents for solution, which is this: What is the secret of the absorbing and passionate devotion which dolls inspire in the breasts of little girls? It is no answer to reply that little girls are fond of dolls for the same reason that, according to Dr. Watts, dogs delight to bark and bite, "for 'tis their nature to," for the point of the inquiry is "*Why* is it 'their nature to'?"

Some explanation has been attempted to be given by Mr. Herbert Spencer in his book called "*First Principles*." It would be idle to enunciate Mr. Spencer's conclusions to anyone not accustomed to read philosophical works dealing with inquiries into obscure and complex sources of physical and mental phenomena, since there could be no hope that they would be really understood even if they were to be put into the simplest language in which they could be conveyed. There may perhaps be some present who may be interested by them, so that I will by two or three sentences, addressed to those few persons only to whom

they will be intelligible, indicate the drift of Mr. Spencer's theory. Play he views as a simulation of activities conducing to the ends of life. He supposes that in the process of evolution faculties become developed beyond the range within which they are necessary to subserve the functions of the organism, and that in this case the unemployed energies seek an artificial vent. Very frequently this discharge of redundant energy takes the form of conscious imitation of the useful actions. Thus, for example, one sees in the devotion of little girls to dolls, and in boys' games of chase, an amusing mimicry of the serviceable actions of adult life. This theory applies, as will be observed, to the character of the pleasure which is yielded by a great variety of toys, such as, for example, boxes of bricks, horses and carts, and bows and arrows.

To descend from these altitudes of philosophy, which most of you, no doubt, find to be, like other high peaks, somewhat cold and rugged, to the smooth pastures of common life below, where our path will be softer to the tread. Did you ever hear how an American writer began a poetical effusion about babies with the rhapsody—"How beautiful is babes! so small, and yet so like human bein's!" A fond mother would probably feel aggrieved if anyone were to tell her that her baby was only "like" "a human bein'." She would probably exclaim, as an Irish mother is said to have done to someone who evinced an inadequate appreciation of the charms of babies, "Ah, Sir, it's plain *you* never were a mother!" But it may with truth be said in praise of dolls that they are "small,

and yet like human bein's," since, when new, they ought to possess, as an indispensable requisite for giving proper satisfaction, a full and accurate semblance of humanity.

No doubt a doll, when it has once secured its owner's affections, will retain them long after it has lost its bloom of fresh paint, and when it is bereft of every rag of clothing, and its limbs have been reduced to mere flabby bags, owing to the escape from them of the bran from which their plump, sausage-shaped proportions were derived. And a little girl will still cling with an unalterable affection, which is almost touching, to what was once a wooden doll, but has now degenerated down into a battered and disreputable plug of wood. "Around the dear ruin each wish of her heart entwines itself verdantly still." But a doll, to win approval, must, in its original and unimpaired condition, resemble such people as the little girl who is to be its possessor is accustomed to see. Black dolls would never be accepted here, but they are largely manufactured in England for export to America as play-things for little negro girls, who view a dark skin as of the orthodox and only proper colour. Blue-eyed dolls are favourites in this country, and they have been more fashionable than ever, according to the experience of toy merchants, since the time when the present Queen came to the throne. They might naturally be expected to be popular in the northern regions of Europe where fair complexions and blue eyes prevail. In Italy and Spain, dolls with black eyes are the most approved, as being more in accordance

with what is usually seen in real life in those countries.

The facts which have just been stated about dolls' eyes have been gathered from no less grave an authority than that of a Blue-book of the House of Commons. Some little time ago a glass manufacturer of Birmingham was called as a witness before a Sélect Committee of the House of Commons to give evidence on certain subjects relating to his trade, and incidentally to these he mentioned the particulars which have been stated with reference to the comparative popularity in different countries of the various colours of dolls' eyes. The manufacture of these articles is a not altogether inconsiderable business, since the same witness who has been already quoted said that he had received on one occasion an order for five hundred pounds' worth of such eyes, and it may be of course assumed that a number of other people in the same trade had had similar demands made upon them for satisfying the requirements of the doll market.

The heads of the better class of dolls, and such portions of their arms and legs as are to be visible to the public after they are dressed, are usually composed of papier mâché, which is paper made into a soft pulp, so that it can be moulded, while wet, into any shapes which may be desired. The faces are formed from wax, or from papier mâché covered with enamel and varnished.

Dolls of the less aristocratic order, whose lot is to be cast in cottages, are simply made of wood, and of these, again, there are two grades, those, namely, which have

their full complement of limbs of the orthodox type, working on joints which, although they move uneasily, as though stiffened by chronic rheumatism, are still practicable, and those whose persons are for cheapness formed of mere sticks covered with bits of rag, which the purchaser is invited to consider as representing attire.



CHAPTER III.

THERE is our old familiar friend the tumbler, as he is called, which is rather an inappropriate name to give to him, because if there is any one particular thing in the world which he certainly does *not* do, and cannot be made to do, it is to tumble. All the most cherished principles of con-



duct on which he acts are inflexibly opposed to tumbling. He is complaisant enough to the extent of bowing readily, but persist as you may in knocking him down, and in trying to make him stay down, he evinces

an unconquerable obstinacy in always resuming an erect posture. By indulging a trifling fancy we may discern in the behaviour of this toy a typical illustration of the Mark Tapley spirit of indomitable cheerfulness raising a man's head again and again as often as he has been bowed by depressing influences.

Now what particular property is it in the constitution of the tumbler which leads him to comport himself as he does? Somebody, perhaps, will answer, "Because the weight of the figure is in its lowest part." Granting that the fact is so, a reply will still be wanted for the further inquiry which necessarily follows as to why the circumstance in question obliges the tumbler to stand upright. "Because," it will be rejoined, "the heaviest portion of the figure being in its nethermost extremity, that region, naturally, by its own weight, sinks to as low a position as it can reach, and stays there; and when the base of the tumbler is thus brought as close as possible to the surface of the table, the head cannot but be highest, and the whole body upright."

This explanation is perfectly sound as far as it goes, but are you quite sure that you fully understand its why and its wherefore, and all that it imports? For captious critics might take exception to the allegation that the tumbler keeps upright because the lower part, being weighted, naturally assumes the lowest position. They might say that the word "naturally" seems to imply that heavy things have a tendency to fall downwards of their own accord, that is to say, that they are actuated by something like a will and habit of their own. They would add

that such a representation as this is objectionable, as being likely to give rise to mistake or obscurity as to the real fact, which is of an exactly opposite character, namely, that heavy things so far from moving at all by their own inclination, independently of compulsion on the part of some distinct agency outside themselves, seem to do their best to resist disturbance, and that the degree of their reluctance to stir exactly corresponds with the amount of their weight; so that a proportionately greater force would, accordingly, have to be applied to induce a ponderous body, although unsupported and quite untrammelled, to tumble earthwards than would suffice to start and bring down a lighter object.

This statement is true, since heavy bodies have in effect what is called a "*vis inertiae*," or as it may be translated, a strength of immobility, in proportion to their weight. The phrase in question may be demurred to as being vague, and therefore undesirable, and as even conveying, in one sense in which it may be taken, an idea which is downright inaccurate, since it seems to suggest energy rather than apathy. It might be construed as importing what is not true, namely, that inanimate bodies, being constitutionally lazy, exercise of their own pleasure a force created of their own will which they oppose to any agency which seeks to disturb their rest.

Leaving these ambiguities of language which it was as well just to notice in order to prevent their introducing some muddiness or other into our ideas, which, to be worth anything at all on any subject whatsoever, must, as a first essential necessity, be quite clear, we

may proceed to say that the force which makes heavy things fall is that which is so familiarly known as "the attraction of gravity." Now the attraction of gravity being one of the most important actors on the world's stage, and not only that, but one of the grand Potentates by whom the Universe is swayed and regulated, it will be an interesting subject for consideration. If this toy be taken as a text, a discussion on gravity will be strictly apropos to it, since the whole performances of a tumbler are exclusively concerned with the action of the force in question.

Every single thing of every kind which the world contains is unremittingly acted on and kept in its place, or moved from it, as the case may be, either directly or indirectly, by the attraction of gravity. So is the world itself, and as far as we know so also are all the stars. Everything about us, together with our own selves, and everything in the heavens, would be sent flying anyhow and any whither, in undignified and tumultuous confusion through space, and there would be a general collapse and crash of the whole universe, if the power of the attraction of gravity were to be suspended, or even in the least degree relaxed, for a single instant. It is a matter, therefore, which is worthy of our attention, as constituting a material element in the stability of the general arrangements of creation upon which our existence at every moment depends. If you comprehend the mode of action of this great force you will understand the working of this toy, and to put the matter both ways for the purpose of impressing it on you the more, it may be added that until you are thoroughly capable of understanding the springs of conduct of this

simple plaything, you can form no idea of what the attraction of gravity is, nor can you make a single step towards the acquisition of even a rudimentary acquaintance with any one of a whole catalogue of subjects of which no one of intelligence should remain ignorant.

Now, first of all, what does the expression the "attraction of gravity" mean? Gravity means weight, and attraction mean "drawing towards"; the phrase, therefore, implies that everything which has weight endeavours to draw every other thing which has also weight towards itself. From this the corollary, or logical consequence, obviously follows, that every such source of attraction is, in its own turn, exposed to like influences. If this be true, and it certainly is so, then, since all of us who are present weigh something, a force of attraction must reside in each of us, and be exercised upon the rest of the assembly. Everyone here is actively, though unconsciously, exerting a force upon every other individual of our party, and upon every object in this room, and also upon the walls, floor, and ceiling. Moreover we are all of us, at this very moment, keeping this force at work upon all other rooms, and their contents; but we may very well confine our attention to the state of things at the particular spot where we are met.

Now why, if it be true that this mutual attraction invites and urges a general and close approach, do we not each of us glide by one consent into our next neighbour's arms, and stay there for ever, or why don't we at any rate feel an impulse to do so? Because we are restrained from any such procedure by

other forces which tend to drag us in the opposite direction. You attempt to draw me towards you horizontally, but the ceiling strives to hoist me upwards ; the floor tries to haul me down, and the walls to pull me four ways at once. These forces neutralize one another, that is to say, they counteract and thus destroy one another's effect, so that I remain still just as if no force at all was acting on me, like the donkey who stood motionless between two bundles of hay of equal temptingness. If the forces were strong enough, and the coherence of the various elements of my personality less robust than it is, I should be torn in pieces, and a general scramble would take place for the fragments of the bone of contention which I already constitute.

Conceiving, however, the general result of all these warring attractions, when acting at any particular moment on some given object, to be such as would cause it to stir if it were not restrained from so doing, still, no locomotion may in fact ensue. For with the very first inception of any start, and indeed before any overt act of this kind can be even initiated, another force, that of Friction, with which we shall have to make some further acquaintance hereafter, is called into being, and has to be reckoned with. The force of friction is one which varies in energy with the particular conditions which give birth to it, but whatever the amount of its power may be in any specified case, the whole of it is invariably put forth in direct opposition to motion. If, therefore, the balance of the various attractions of gravity which are at this moment contending for the mastery over any object, say the table before us, were to be in favour of its transference to the other side of the room,

the victorious influence would still have to settle accounts with friction before it could generate any practical effect.

But, you may ask, is it really true, as was alleged just now, that all bodies having weight attract one another? It can be shown in a thousand ways that such is the case. The following is a common proof, which is reached by actual experi-

ment. Suppose that you have a high cliff overhanging the sea, or a plain, and that from its edge you drop a string with a weight at its end, thus forming what is commonly called a plummet line, and allow this to dangle free in the air, so that it is easily to be swayed in a lateral direction by any sufficient force. It will be found that the string will not hang perpendicularly, but slanting a little towards the cliff, because this latter, having very great weight, will attract the leaden ball and drag it towards itself. In



this case, you see, the cliff is enormously heavy, that is to say it has a great attractive power, which is not counteracted by anything immediately opposite to it, and equally close, on the other side of the string.

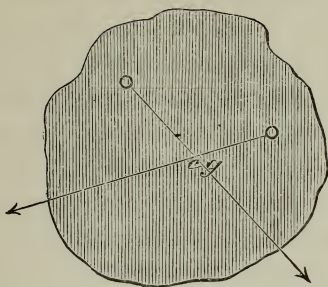
Why gravity attracts as it does nobody knows, so that of course I cannot explain it. But although we cannot detect the why, we can to some extent mark the how, that is to say the mode or course in which the force in question acts. To understand this, a clear no-

tion of what is meant by the expression "the centre of gravity" must first be acquired.

The centre of gravity of any body is the point about which all the parts of that body balance one another in weight. It follows from this definition, as a little consideration will show, that if the point in question be suspended from, or propped by, some adequate support placed in a vertical line above or below it, the body will remain at rest. A further consequence will also be found to be involved by the terms of the same definition, namely, that if the point in question be not thus sustained, it will immediately make its way towards the lowest position which it can reach, and will continue to pursue this course until it is definitively arrested by some impediment which it is unable to overcome. When it is thus brought to a standstill, the body of whose gravity it is the centre will obviously remain at rest. For its several parts, balancing one another round its centre of gravity, neutralize whatever independent and separate power any one or more of them might otherwise possess of causing further motion. Their various forces are, in effect, as you see, all spent upon a combined effort to depress the centre of gravity, but this, having got as far down as it can go, is no longer amenable to coercion.

To illustrate by an example what is meant; take any object you please; but something of an extremely simple form, such as, for instance, this board, will be the most convenient. Its thickness, being very small in comparison with its length and breadth, may be neglected, so that the two latter dimensions only need be regarded. Make a hole in it anywhere, and then sus-

pend it, as may be readily done by this pin, in any such manner as that it may swing with perfect freedom. Since



it is thus put at liberty to hang in whatever posture may be most in conformity with the general result of the forces which govern its movements, it necessarily assumes the particular position in which the weights of the parts on the right and on the left of the pin respectively balance one another. If the two sides of the board did not mutually counterpoise, the heavier would go down, and in so doing would pull the lighter up, just as happens with a pair of scales when the weights in the two saucers are unequal. And the board, like the scales, would be kept in continuing unrest until a balance was established. But the board, as you see, now hangs contentedly quiet, which shows that its centre of gravity is at some point in the perpendicular line between the pin and the ground.

Now suspend the board from any other point in it, taken at random, such as this, for example, and let it hang freely as before. Thus. After swinging a little, like a pendulum, till the result of the forces which are in action has been determined, it becomes stationary

and at this juncture its centre of gravity must, by the same reasoning which was employed just now, be somewhere in this perpendicular line let fall from the pin towards the floor. But we have already seen that it is also in this first line, and if it is to occupy a place in both, it can only do this by being situated at the sole exact point which is common to both lines, that is to say where they cut one another, which is here, at *c g*.

Now the force which anything exerts by its weight, that is, in other words, the attraction which it exercises by means of its gravity on other objects which also have weight, behaves precisely as if it acted from the centre of gravity of the body whence it emanates. So that in estimating the effect which this force does, or must, produce, it may be considered as operating just as if the centre of gravity of the body which generates it were its actual and exclusive source. This is, virtually, the real fact.

Remember all this time that we are speaking of the centre of a body's gravity, which is quite a different thing from the centre of the same body's form. The centre of a body's weight, or gravity, need not by any means be at the same point with that of the middle of its figure. The body, as in the instance of the persons of men and women, may be made up of parts consisting of different materials, some of which may be heavier than others, and if this should be so, the centre of the weights of the several portions taken together will not necessarily fall at the middle of the whole group. In many cases, indeed, the centre of gravity of an object is not within the external surface of its body at all. The centre of gravity of a ring is at

about the middle of the space which is left open for the finger, and that of a man's hat is somewhere or other in the tract which is occupied by the wearer's head. It is true that in the case of a symmetrical figure, such as a round ball or a square die, the centre of its gravity coincides with that of its figure if the object be homogeneous, that is to say if it be wholly composed of one material only, or of materials which are of uniform heaviness throughout, because in such instances as this the weights of the various parts are manifestly disposed in precisely equal proportions all round the middle of the space which they occupy.

Let me now give you an illustration of the course in which the attraction which is exercised by the



gravity of anything and everything acts, as has been described. Here is an umbrella, and here, at a short distance off, is a pea. What do we now know of their relations to one another? This, that the umbrella is attracting the pea and the pea the umbrella, and that if they were not forcibly held back by other agencies they would move towards one another, and remain locked in a perpetual embrace.

This opportunity may be taken for adverting to a

main fact and feature of the subject which we are upon, which is this, that the force of the attraction of gravity is proportionate to the distance through which it operates, as also to the quantity of matter, called the "mass," which exerts it. The latter condition is the one with which our present inquiries have immediately to do. In lead, the particles which compose the metal are packed together far more closely than is the case with the materials which make up a feather, so that the former exercises a much more powerful attraction, bulk for bulk, than the latter does. Similarly, the umbrella brings into play a greater force of attraction than is wielded by the pea from having a larger quantity of material in its personality. The attractions with which the umbrella and pea operate on one another are reciprocal, but, as we have seen, not equal in power.

Suppose now that the pea were quite free to move, and to go to the umbrella, at what point would it join it? At, or as near as possible to, the centre of gravity of the umbrella, since, as was stated just now, the whole attraction of the umbrella may be regarded as if it were concentrated at, and worked from, that point. Why is this? Because the attraction of the umbrella as a whole is, of course, and must be, nothing more nor less than that of its mass; and that of its mass is the sum of the attractions of the several component items of its various parts, each of which is, in its way, a magnet. If these separate forces of attraction be represented upon paper by lines traced along such tracks as they must really pursue, the general pull in which they unite will be visibly seen to be necessarily of the character which has been assigned

to it. The forces are, of course, innumerable, since each little several atom of the wood, steel, and silk of the umbrella is in itself a tiny loadstone. If, therefore, every such force were to be separately represented, the lines would be absolutely countless. But a true idea may be given of the general tendency of the whole by the delineation of a few of them as indicators of the proceedings of themselves and of their more immediate companions.

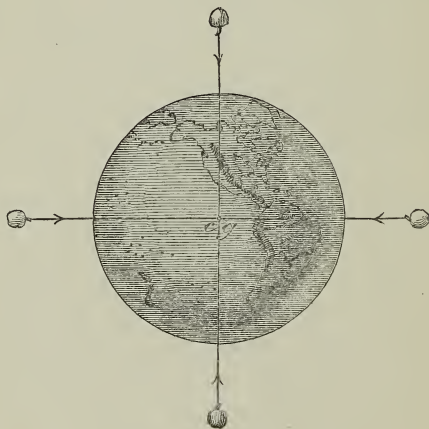
Now conceive the lines which we have drawn to be strings all pulling the pea at once. You can see at a glance that the result of the combined tug, if not rendered of none effect by friction or by some other counteracting agency, would be to land the pea at a spot about half way up or down the length of the umbrella. A little consideration would show you that the point in question must necessarily be the centre of gravity of the umbrella. And a little further examination of the matter would demonstrate no less clearly that the precise road which the pea would be bound to take would be along a straight line joining its own centre of gravity with that of the umbrella.

The conditions which would govern the procedure of the pea would, if allowed free play, regulate the conduct of any other body moving under the influence of the attraction of gravity towards an object heavier than itself. The path to be followed could be no other than the shortest cut to be found between the two centres of gravity of the objects concerned.

And now let us consider the application of this general and unvarying law to the particular case of the attraction which the earth exercises by means of its

gravity upon everything on its surface, for this inquiry is one which forms an indispensable preliminary to any real examination of the action of the tumbler.

Our globe is, roughly speaking, a sphere, or solid ball, so that its centre of gravity is, as we saw just now must be the case, identical in situation with the middle of its mass, that is to say, at the very innermost heart's core of its substance. Everything, therefore, which the earth's gravity can affect is attracted towards this centre. Now draw a circle, thus, to represent the



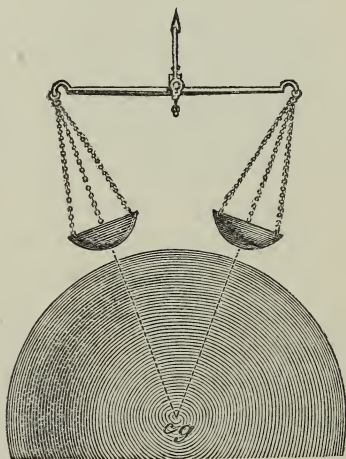
world, or a section of it made through its waist, and say that England is hereabouts, at the top of the diagram, and imagine that at this point there is an apple tree with an apple on it, and conceive the latter to be ripe, and to fall from its stem. Why, as Newton is said to have asked himself, does it fall? It is not accurate, as you have already learnt, to talk or think about falling as if that were an act which the apple,

or anything else, does, or can do, of its own accord. You will remember that nothing ever moves, or stops moving, except under the compulsion of some force. An apple, when its stalk gives way, would, as far as any will of its own could be concerned, stay where it already is, but it is drawn towards the centre of the Earth by the attraction of gravity. When it reaches the ground, it there encounters a bar to further progress, but if it were not thus arrested, it would never stop till it had ensconced itself at the nucleus of the Earth's mass, which is about 4000 miles underneath the spot where we are standing.

Now if England be taken to be at the point of the circle which we assigned to it, then New Zealand will be nearly at the opposite position, at the bottom, that is, of the diagram, and an apple falling from a tree in that country will tumble upwards. Similarly if China be hereabouts to the right, and Peru somewhere in this direction on the left, apples dropping respectively from trees in those parts would fall horizontally.

Here you have the plainest possible demonstration that whenever anything which is free to move obeys the attraction of the Earth, or, as it is popularly expressed, falls, it does not tumble in any accidental fashion, but is simply pulled, as far as it can go, towards the centre of the globe. Loose talk about the natural tendency of bodies to fall, if the terms of such language be examined, does not even amount to a pretence of explaining anything, since the words "upwards" and "downwards" are, of course, merely relative expressions, indicating change of situation with reference to something or other, and not any

absolute direction considered independently. "Upwards," in and for whatever locality it is used, is conventionally understood to imply retreat from the Earth, and "downwards" approach to it. Since these meanings are respectively attributed to the terms in question for all spots on the surface of the world, and throughout all the various attitudes which the globe assumes in the course of its orbit, they can plainly have no more than the restricted signification which has been mentioned. For if their import was not taken to be thus limited, it would comprise changes of place in all directions which are conceivable, and of which half the number would severally be diametrically opposite to the other half. Lines of possible movement are, as need scarcely be observed, absolutely infinite in number,



so that the expressions which have been criticised would, if not interpreted in the narrow sense which has been

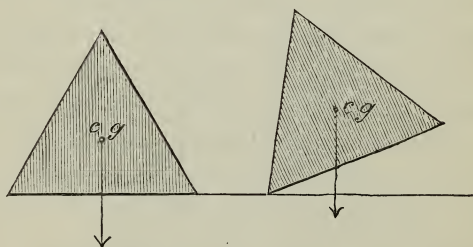
pointed out; be wholly devoid of any real meaning whatever.

For reasons which have now become obvious the saucers of a pair of scales do not hang with their centres in a perpendicular line below their respective points of suspension if the pillar which supports the beam be regarded as vertical. That is to say, lines drawn from those centres to the beam-ends above them are not parallel to one another, or to the scale post, but as they approach the ground they make some slight convergence. This deviation from parallelism, although it is so infinitesimally small as to elude any observations which our senses can bring to bear on it, and defies any tests by which we might endeavour to appraise it, has nevertheless a true existence. Lines drawn as supposed would meet at the centre of the earth, and so of course would the saucers if they could swing so far.

It has been stated that the centre of the globe is the seat of the whole attraction of gravity which the entire mass of our world exercises. The thorough assimilation, in medical phraseology, of this fact by the mental digestion may be promoted if it be administered in another shape in which it will be readily taken up by the intellectual absorbents. The attraction of gravity is found by experiment to be governed by a particular law to which we referred just now, and to which it conforms, under all circumstances whatever, with strict and implicit obedience. This Ordinance of Nature, when expressed, for simplicity's sake, in the most general terms possible, is as follows, namely, that the attraction of the gravity of any given mass wanes

according to a certain well-ascertained scale of degrees which is in precise correspondence with the length of the distance through which the force acts. Now if the surface and not the centre of the Earth were to be taken as the source whence attraction emanates, results inconsistent with the law in question would be given by practical experiments founded on such an assumption as this, showing that an erroneous basis of calculation had been laid.

We have seen that the centre of gravity of any, and every, body is that point about which, if it be supported, the whole mass will balance, and therefore rest quiet and contented. We have also seen that if this point be not supported, it will descend to as low a position as it can reach, travelling along the straight road leading from its own position for the time being towards the centre of the earth. Let us take a couple of instances to show how this occurs in actual practice, and with what results.



Here we have a three-cornered board of the shape of a pyramid. Since it is of a regular figure, and of one uniform substance, its centre of gravity (leaving out of account its thickness which is so small as to be immaterial) will be at the middle of its surface. Set

this pyramid upright upon its base—thus—at the edge of the table. Suspend a string, with a weight at its lower end, from the centre of gravity of the pyramid in such a manner that it may hang quite free. The weight is bound to get as near to the centre of gravity of the earth as it can, and the string by which it hangs must thus represent part of a straight line which, if it were to be continued sufficiently far, would join the centre of gravity of the earth with that of the pyramid.

The pyramid remains at rest. Why? Because its centre of gravity is supported by what may be regarded as a vertical prop, constituted by a line of particles which are a portion of the substance of the pyramid, and which, as it were, form a pillar whose base rests upon the table. If you tilt the pyramid a little up on one side, you lift, as you see, the lower end of the prop from the table. The pyramid, therefore, will not continue at rest after your hand is withdrawn, since its centre of gravity, having been deprived of the support which it gained from the table through the prop, will now move downwards, till the original conditions of stability have been restored. The pyramid may be considerably tilted, yet it will still continue to resume its first position as soon as permitted to do so, provided only that it is not made to bear over to one side to such a degree as that the line dropped perpendicularly from its centre of gravity falls beyond the extremity of the base in that same quarter. When that occurs, the attraction of gravity combines at once with the lateral inclination coming from the tilt, instead of counteracting it, and helps to bring the pyramid down by pulling it round over the terminal point of its base, turning it, as it were, upon a pivot.

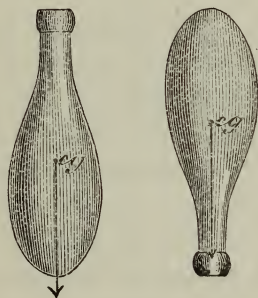
A pyramid, therefore, when standing on its base, has such a figure and "pose" as are calculated to impart to it a resolute conservatism of attitude, since the effect of any disturbance of its equilibrium, provided that this does not exceed a certain definite limit, is to excite an opposing and restitutive action on the part of gravity. A body so circumstanced in respect of its balance is said to be in a position of "stable equilibrium."

It is quite unnecessary to advert to the obvious reasons of a similar, or, as it might, perhaps, be more accurate to say, converse kind, why a pyramid which poises on one of its tips has no stability of attitude, but topples over on its side on the slightest provocation. When it is thus insecurely balanced, with a disposition and destiny, if it rocks at all, to fall irretrievably, it is said to be in a position of "unstable equilibrium."

Our examination of the conditions on which the stability of a pyramid depends has incidentally rendered us able to discern at a glance why an overloaded waggon will upset on a bit of road slanting sharply towards the ditch on either side, which it would traverse without risk or disaster if it were empty. And there can be no one who has gone along with what has been already said who must not fully understand why an egg is contented enough to lie lazily on its side, but cannot be made to stand in what may be called an upright attitude. You recollect the old story of Columbus and the egg. Some bets were made at a party at which Columbus was present that he could not make an egg keep erect on either of its extremities. He cut

the knot of the difficulty as summarily as, according to the story alluded to by the phrase which has been just this moment used, Alexander the Great did the Gordian Knot with a slash of his sword, by dabbing the egg down on the table so as to stave in one of its ends. He thus supplied it with a broad base on which it could steady itself. This solution of the problem was unsatisfactory, inasmuch as the egg did not after all stand on its end since it had none left for the purpose.

We can do something which is akin to the egg-feat, which will bring out into clear view the precise nature of the difficulty which has to be encountered, and the only plan in which it can be met, if we balance a soda-water bottle on one of its ends. The general appearance of



such a bottle is suggestive of a great glass egg. It will not stand on its oval point, but will keep erect on its other extremity, because a perpendicular line drawn from its centre of gravity, which is at about the middle of its stomach, falls within the limits of the circular base which is afforded by its mouth.

In many of our habitual bodily gestures we unconsciously, and automatically, supply illustrative demon-

strations of the fact that a posture of stable equilibrium is intrinsically adverse to motion, while one of unstable equilibrium is essentially favourable to it. For example, how does a man who is intending to walk across the room dispose himself, in preparation for that enterprise? Does he set his legs as if they were the two limbs of the letter V turned upside down, that is to say, pyramidically, with his body so poised above them as that his centre of gravity, which is probably somewhere within the course of a straight line drawn horizontally from about the middle button of his waistcoat to the small of his back, shall be supported by them in a position of stable immobility, in which it will desire to remain comfortably quiescent, and from which it cannot readily be dislodged?

By no means. He begins by leaning forwards, thus throwing his centre of gravity in front of, so that it is therefore no longer perpendicularly over, the base which is constituted by his feet. He thus brings his body into a state of unstable equilibrium which would cause it to topple over, were not a fresh base immediately supplied by the putting of a leg forwards. That the position before the moment when the leg is thus advanced is one of unstable equilibrium may be readily ascertained by suspending further progress when the attitude of leaning forward, which is preparatory to motion, has been assumed, and before the step which should succeed this action has been taken. It will be found that the posture of the body at the juncture in question is such an one as cannot be maintained without some exertion to prevent falling.

Assuming, however, a step to have been taken in the

usual manner, this is only introductory to the assumption of a fresh condition of unstable equilibrium by which the subsequent advance of the leg which is behind will be necessitated. Walking is thus seen to be in fact a continued series of small feats in balancing, for the accomplishment whereof the performer's original condition of stable equilibrium is purposely and unavoidably abandoned for a transient state of an opposite kind which is such as to be preparatory to motion. The tendency to fall which is thus induced is instantly corrected, as often as it occurs, by a momentary resumption of an attitude of stability, to be immediately afterwards exchanged for the instability which is indispensable as a prelude to fresh progress.

A rapid alternation, such as has been described, of gestures accurately adjusted to the purpose which they are to promote, and their efficient achievement, demands an adroitness which, although it is in the first instance acquired, like one's native language, by insensible degrees, and is gradually brought to perfection by habit so that at last it is automatically exercised, is none the less a real feat in gymnastics, the capacity for which is more or less suspended or destroyed when the brain of the performer, through drinking, or any other cause, has lost its cunning.

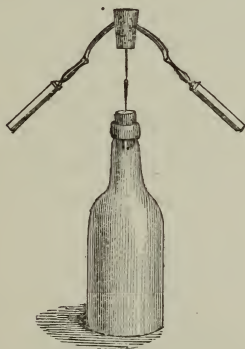
It is due to Dame Nature not to part from the subject of walking without gratefully acknowledging the provision which she has made for saving us unnecessary exertion by giving us bends at our knees. A little examination of the matter will show that it is owing to this contrivance that the advance of our centre of gravity, when we walk, is by a softly undulating line. Were the

knees stiff, the centre of gravity would have to be raised higher at each step than is necessary when the joints in question are flexible, so as to allow the foot to clear the ground ; for to brandish the leg round with a semicircular sweep, which would be the only other alternative, would be still more inconvenient. That this would be so may be visibly demonstrated by walking a cheap doll, whose anatomy is too incompletely developed to include practicable knees, across a table. The line of progress of the centre of gravity of a man similarly conditioned to such a doll, through having stiffened joints, or from having lost his legs to above the knees, must be, as will be found, a series of arches, so that his gait will be less flowing, and far more laboured, than it would be if the usual facilities for walking were available to him.

The principles on which our tumbler, who gave occasion to this long disquisition on gravity, conducts himself, have long since, as it may be hoped, become sufficiently manifest. His figure is made of light materials, and a concealed weight is introduced near its base in such a manner as to bring his centre of gravity to some point very near the lowest part of his person. The figure being so prepared and trimmed, recovers itself, after it has been caused to rock to either side, precisely as a pyramid does when tilted as just now described, and for reasons which have been already enlarged upon. A boat, of course, is ballasted on just the same principle. A tumbler, if he were set to stand upon his head, would really act up to his title, and do nothing but tumble, for the same reason that an egg will not stand on its end, or a teetotum, when at rest, on its peg. He would have the unstable

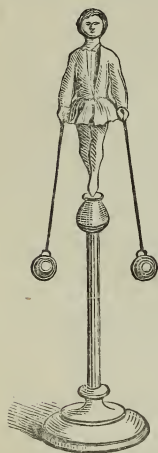
equilibrium of a man perching on one wooden leg, or on a single stilt.

If a teetotum be so constructed as to have its centre of gravity below the point of the peg on which it spins, it will then stand erect, even when at rest. This can easily be proved by experiment. Any bit of cork, or other convenient substance, may be made into a teetotum by simply sticking a pin through the exact middle of its mass. Of course it will not keep upright of its own accord as it is now, but its disposition in this respect may be altered by the addition to it of weights suitably adjusted for the purpose. Such adjuncts will readily be furnished by two



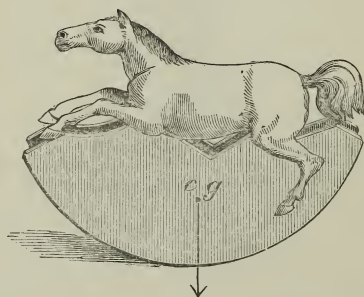
forks stuck into the cork on opposite sides of it in such a manner as to make with one another an angle like that which is formed by the legs of a pair of compasses when a little opened. The teetotum will now be found to balance securely if it be set to poise with its pin resting on a stick or on any other support which will allow the forks to swing as they please without touching anything. The secret of its newly

acquired faculty of maintaining its equilibrium is that the centre of gravity of the cork and forks taken together, and constituting, as they in effect do, one figure, now falls at a spot which is lower than the point of the pin.



Here is a more ornamental example of the same principle in the shape of a common toy in which a dancing lady pirouettes on the tip of one toe, through the aid of bullets attached to her waist by stiff rods, so that her centre of gravity when she is thus accoutred is below her feet. It is no less easy to construct a top which will stand upright, although stock still, upon its peg, as will be shown bye and bye.

A rocking-horse, when at rest, maintains its upright position for the same reason, speaking generally, that the tumbler does. There is no rocking-horse among the



collection of things which is before you, because it is rather a cumbrous thing to take about, and we do not particularly want it, but here is what looks like a rock-

ing-pony. It is, as you see, a sort of hybrid article, partaking about equally of the character of a rocking-horse and of that of a tumbler. My reason for presenting it to you is that it aptly introduces the topic of weighing by scales, as to which I wish to say something. Scales are very popular as toys, for I notice that bushels of them are sold in the Lowther Arcade at a penny apiece and upwards, and they are therefore entitled to notice this evening. The connection between this toy and a pair of scales is not, perhaps, at this moment, self-evident, but it will reveal itself in the fulness of time a few minutes hence.

As introductory to the subject of scales, the question must be asked, "What is weight?" A true answer to that inquiry will now be readily forthcoming on your part, and will be of this kind. The weight of anything is the force which it exerts in endeavouring to get towards the centre of the earth. This endeavour represents, and is the accurate expression, both in its direction and in its energy, of the attraction which the earth, by means of its gravity, exercises on the body in question. The body would go on moving, as we know, towards the centre of the earth without ever stopping until it reached that goal, unless its progress were arrested by some means or other. We cannot easily pronounce with what exact degree of force it moves unless and until we stop it, but if we interrupt its march by interposing some obstacle which it has, if possible, to overcome, we can appraise the power which it exercises in the attempt to do so. This may be done in many ways, but the most common and convenient method is by the familiar agency of a pair of scales.

Here is a paper containing sugar. I hold it up in my hand. It is attracted towards the centre of the earth, but makes no movement in that direction simply because I don't just yet permit it to start. I now release it from the durance of my fingers. It is instantly obliged by the compulsion which the earth employs to set forth, or, as the proceeding is commonly termed, falls.

Now let me just this once more, and it shall be for the last time, beg you to beware of the confusing error which many people, in spite of repeated warnings, allow to retain a grip on their understandings, that anything falls of itself. Nothing originates its own motion a bit more than a wooden leg goes out walking of itself, and a pound of sugar is no more likely, through any internal capability and will of its own, to hurry from my hand to the floor, than it is to get up and dance a jig. It is strange that a fact which one would have thought was self-evident, namely, that everything is and must be passive, and that nothing but force originates motion, should have ever required demonstration. It was not, however, clearly realized and accepted until Kepler won for it the position of a familiar truth.

Now the earth attracts bodies with a force which is exactly proportionate to their mass, that is to say to the quantity of matter which they contain, so that objects which have more substance in them are attracted with a correspondingly stronger power than those which have less, or in other words, the former are, as it is familiarly expressed, heavier than the latter.

Here is a second packet of sugar containing twice the quantity of that in the first paper. It strives to go to the

ground, that is to say, as far as it can get towards the centre of the earth, with a force twice as great as that by which the first packet was animated, because it contains double the quantity of matter. If the parcels were to be allowed to fall upon the floor, it would be very difficult indeed to form even an approximate estimate of their comparative or respective weights, but we can appraise these with complete ease and accuracy by interposing in the path which each of them pursues when released from the hand one of the saucers of a pair of scales.

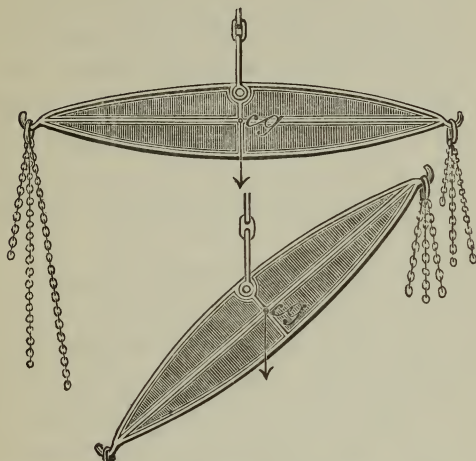
Any downward pressure exerted by the packet of sugar will now be spent upon the saucer beneath it. Into the other saucer we put some substance whose mass will evoke from the earth's gravity a certain quantity of attracting force the amount of which has been ascertained, and which we call by some distinctive name indicating its precise value in point of strength. This criterion of the degree of attractive force we term a weight. Such tests are usually made, for handiness, of iron or lead, or at any rate of some metal or substance which may be readily so fabricated as to contain any prescribed mass of matter in an exact and compendious form. We add to, or take from, the freight of one saucer or the other as may be most convenient, until the two loads balance one another in downward pressure so that equilibrium becomes established. In the case of a lb. weight, the block of iron which is used acts with the particular degree of force which people have agreed to call a pound. If it exactly balances the sugar, the latter is said to weigh a pound. The real nature of the proceeding in so extremely simple a matter as the weighing out of a pound of sugar appears to be, demands,

as you can now see, some little examination before it is thoroughly understood.

The mechanism, too, of a pair of scales invites consideration. The beam whence the saucers are suspended, to prove satisfactory in use, should possess three main good qualities. It should be strong; it should be long; and it should be light. It should be strong, because it is in an analogous position to that of a stick which a man strains over his knee for the purpose of breaking it. The weights in the saucers represent, in the tendency of their action, the pulls exerted by the man's arms, and the fixed point at which the beam is supported corresponds, under the circumstances, with his knee. But if the beam were to bend, as it would do, when dealing with heavy weights, if it were not strong, this would disorganize the whole process of weighing, and would vitiate the accuracy of the indications given. The machine will be more lively and sensitive if its beam is tolerably long and light for mechanical reasons, which, as being concerned with the elementary principles of the lever, are not far to seek. Lightness, however, is not an easy quality to preserve in association with the inflexible stiffness which, as has been said, can by no means be dispensed with. Aluminium, one would think, would be a good material for scale-beams, as it is in a marked degree both light and rigid.

A common method of combining as far as possible the three elements of efficiency which have been mentioned is by the employment of a beam of an attenuated oval shape like that of an almond. A beam of this kind is frequently to be seen suspended from its upper

surface, or from a pin passing through a hole just under that surface, at a point immediately above the middle of its length. Since it is of a perfectly regular and



symmetrical form, its centre of gravity will be at the centre of its mass, that is to say, at the middle point of its length, and also at that of its depth between its upper and under surfaces. For the sake of simplicity, it will be as well to regard the beam as extremely thin, and treat it as if it were merely a surface without any depth at all, which, for all present purposes, may be done without error. Every such beam is in fact made as thin as is compatible with the maintenance of an unyielding firmness of structure, in order that it may be as light, and consequently as sensitive, as possible.

Now the centre of gravity having the situation which has been already pointed out, does not coincide with either of the spots at which, as has also been observed, the pivot on which the beam swings, or the

attachment whence it hangs, are often placed. The action of a pair of scales whose beam is so swung as has just been described is necessarily faulty. You will readily see that this must be so. Make this horse prance by raising or depressing for a moment either end of the crescent-shaped frame on which he stands. As soon as the effect of the temporary rocking motion which has been caused is worn out, he regains a settled composure by reverting to his original position, which is the only one in which, when quit of disturbing constraint, he will acquiesce.

The governing principle of his conduct in so doing is transparent. For consider him as he is when at rest. Here (see page 78) is the point on which, when quit of all external influences, except that of his own gravity, he reposes. His centre of gravity must therefore be in a perpendicular line above this point. Now when you make him rear or kick, you, as an obvious consequence, which will manifest itself on experiment, throw his centre of gravity to the right or left, as the case may be, of the perpendicular line drawn upwards from his point of support on the floor or table. The result of so doing will be to incite the force of gravity, as soon as it regains free play, to reinstate the figure in its first posture. It is the old, and now wearisome, story of the pyramid and of the tumbler over again. Far be it from me, therefore, to enlarge upon it anew.

The beam of an oval scale, unless it be hung from its centre of gravity, is, as you see, by its innate disposition, and in its real effect, a tumbler. But in case this should not be quite plain to everybody at the first onset I interposed the rocking-horse between the two, since he

is half-brother to both, resembling each of them to some extent in respect of the gravitating qualities of the frame on which he works, so that when the transition is made from one to the other through him, he does something towards taming down any violence which might otherwise be thought to exist in the representation that the tumbler, the pyramid, and the scale of the beam are, mechanically speaking, a triplet of twins.

We have not yet, perhaps, followed out as completely as we ought to do, the inquiry why the action of a pair of scales whose beam does not swing on its centre of gravity must of necessity be faulty. The question is not so abstruse as that it would require the ingenuity of a Queen of Sheba to propound it, or the acumen of a Solomon to give the answer. Imagine the saucers of a pair of scales, hung from a beam which swings as has just been supposed, to be loaded with unequal weights, so that one rises, and the other descends. The beam therefore assumes a slanting instead of a horizontal position. It has been compelled to accept a change of attitude, but while so doing it has exerted a continued and increasing resistance to motion on its own account. Its disposition, mechanically speaking, is like that of the impracticable people who oppose the inertia of their own heavy stolidity to progress, however legitimate, in any direction, simply on the ground of its being progress.

Now a pair of scales, emblematic as it is of Justice, should, in consonance with the first essential principle of judicial impartiality, be free from any partisan spirit, and behave as a mere passive registrar of the fact of the

equality, or of the precise degree of the preponderance, of one or the other of the two forces whose mutual relations to one another it is to determine and display. It should wholly and exclusively surrender itself, with a completely passive "abandon," to the natural influence of the weights with which it is concerned. But in this case the beam, literally speaking, throws something of its own weight into the scale. For the rise of one saucer, and the fall of the other, are both equally discouraged and impeded, and the difference in the weights of their respective loads, which it is the particular duty of the instrument to determine, is to some extent falsified.

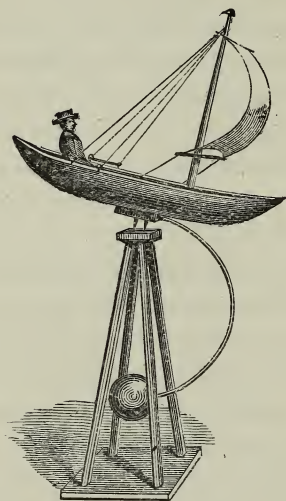
In rough measurements of heavy goods, where slight inaccuracies are not material, the error introduced by the personal proclivities of a beam not revolving round an axis passing through its centre of gravity may be disregarded as immaterial, but if the same instrument were to be employed for appraising small modicums of delicate substances, such as a chemist deals with, the misrepresentations of weights might become of serious consequence.

The nature of the perversion of truth which, albeit small, would really occur, may be caused to reveal itself by means of a scale-beam designedly so formed as to magnify the error into proportions large enough to be readily visible. Here is a pair of scales with a beam which is of a purposely exaggerated breadth; it is, indeed, square. Anyone who may have occasion to take some medicine of so active a character that it is only to be used in minute doses, carefully limited, had better not have it weighed out with a pair of scales like

this. I will first of all, as you see, put a drachm weight into one of the saucers of a pair of banker's scales, which are of necessity truthful in their indications, and I put enough of a white powder, which you are invited to imagine is a powerful drug, into the other saucer, and, as you observe, they balance. I transfer both of these to the other scales, and you can now, as you see, add some further quantity of powder without being cautioned by any note of warning given by the beam, that you have got more than the single drachm which you suppose. If you pivot the beam on a peg at its centre of gravity, upon which it can turn with freedom, it will become healthily sensitive, and its judgments will be pronounced with unalloyed good faith.

Now to make something like a clean sweep of the subject of scales, while we have got our hands in for manipulating the problem of the various conditions which produce equilibrium, it may be as well to advert to one remaining possible state of circumstances not hitherto dealt with, which is that of a beam at rest, but not in a horizontal posture. It may assume this attitude either from swinging from a point to the right or left of the middle of its weight, or from having one of its saucers freighted more heavily than the other. Can you bring such a beam to a state of horizontal equilibrium by adding a weight to the side which is already the heavier? This would appear to be a mechanical paradox, corresponding with a moral one which may be put as follows: If a man has formed a determination to do some particular thing, can you by making that resolution stronger still, induce him to act in direct contrariety to it? Such an attempt would

not seem to promise well. But one of the commonest and simplest of all toys, which we may notice here, discloses a clue to the problem, and shows that there may be more to discern even in a child's plaything than negligent eyes are apt to observe.



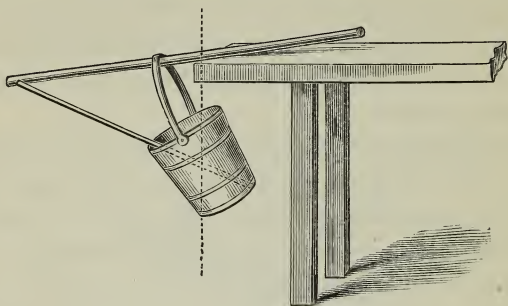
Before you is a wooden ship. Its centre of gravity is at about the middle of its hull. If you set it to rock at the edge of the table, or on this stand, resting it on the pegs which project from the hinder part of the keel, its centre of gravity which does not come perpendicularly over its point of support, being unsustained, instantly makes its way downwards, and the vessel comes to grief upon the floor. But take this bent wire with a bullet at its end, and fix it towards the front of the ship on the side towards which there is already so strong a tendency to fall, and, oddly enough, as it seems,

the added weight, instead of aiding and abetting that inclination, is found to counteract it. The ship now rocks in perfect security, having an equilibrium which is indomitably stable, since however much and often this may be transiently vanquished by some extraneous agency, it never fails to reassert itself as soon as circumstances permit.

The explanation of the phenomenon is almost transparent. The centre of gravity of the vessel, apart from the weight, is, according to our supposition, somewhere amidships. But when I feign to add a weight to the side which is already the heavier, you must remember that as far as relates to the conditions of balance, the ship, with the appendage which is fastened to it, constitutes in effect but one figure: and you will observe that the curve of the wire is so adjusted as to bring the centre of gravity of the whole affair underneath its point of support. The real truth is thus arrived at, that although a pretence is made of supplying a further weight to one side it is in reality bestowed upon the other.

The seeming physical inconsistency of causing equilibrium to be gained by ostensibly strengthening the conditions which are most opposed to it is also illustrated by an old familiar trick, which is given in most of the common children's books of games and pastimes, such as the "Boy's Own Book," and "Parlour Magic," &c., and is done as follows. A bucket of water is suspended from the end of the free portion of a stick which partly rests upon a table and projects for some distance over the edge. The stick not being fixed or propped in any way, the bucket to all appearance hangs from no adequate support.

The illusion is created by triggling a second stick against a notch in the first one, and also against the bucket, and so disposing it as that it thrusts the latter



nearly altogether under the table. The bucket cannot now fall, because the first stick, as may be observed, can neither slide along its surface length, nor turn over at the edge of the table, as on a hinge, without raising the centre of gravity of the bucket. Under the circumstances, therefore, which have been brought about, the weight of the bucket is enlisted in the cause of resistance to motion instead of in that of producing it, so that the whole situation is one of immobility.

We have talked about the attraction which the Earth exercises by its gravity, and we have also discussed the method in which, by means of scales, the power of this force may in many cases be estimated. Now with reference to these topics, suppose that some troublesome person like the inquisitive little Caffre boy who has attained a conspicuous place in history by his perplexing questions to Bishop Colenso were to ask you whether the weight of the Earth can be ascertained and if so what it would be, how would you answer?

There are probably some people who might reply that the Earth cannot possibly be weighed, for that no tackle could be got to do it. They would say that such an operation would be in more senses than one on too large a scale. They would add that the unknown weight, whatever it may amount to, must reach a high figure, because let alone the hidden contents of the inside of the globe, which are probably substantial enough, there are so many ponderous objects on its surface. So that although the precise weight of the whole concern may not be within reach of even a conjectural estimate, it certainly is not quite the sort of thing which one would like to have dropped on a tender toe.

Now the first of these answers, namely, that the Earth cannot be weighed, is wrong. The tackle required for the operation exists. Scales are not by any means the only instruments for estimating weight. The same purpose is answered by an elastic metal spring, which indicates by its degree of collapse the precise amount of any weight by which it is depressed. The Steelyard, again, although it may be viewed as only a modified form of a pair of scales, is not precisely the same thing. Mercurial and aneroid barometers are also mere weighing machines. In the case of the former of these instruments the indications of weight are given by the height, from time to time, of a column of mercury which is supported by the pressure of the atmosphere, that is to say, by the weight of the air. The aneroid barometer furnishes the desired test by means of a collapsible metal box kept partially expanded by a steel spring. The strength of the effort

which the atmospheric pressure is able to put forth in squeezing the box against the opposition of the spring is made to show itself upon an index.

Another device for weighing may be adverted to. It is often requisite, for the purpose of ascertaining the quality or character of some given liquid to determine its specific gravity, that is to say its heaviness, as compared, bulk for bulk, with a particular standard, namely, that of distilled water. This object is accomplished by plunging into the liquid a hollow tube marked along its length with a graduated scale, and equipped with a sufficient weight at one end to cause it to swim in an upright position like a float used in fishing. The greater or less depth to which the instrument immerses itself forms a gauge, through a principle which we have no time to discuss here, of the specific gravity, or precise weightiness, of the liquid. The usual process of weighing is in this case apparently reversed, since the scales are, as it were, put into the liquid, instead of the liquid into the scales.

There are many other means of weighing besides the familiar ones of which I have just reminded you, such as, for example, that which is grounded on observation of the time occupied by the swing of a pendulum; which process, though mentioned last, is perhaps the most important of all, as it is one of the methods by which we are enabled to determine the gravity of the world.

Sir Isaac Newton calculated the weight of our globe, and not of it only, but of many other stars also. If you look at his monument next time that you go

into Westminster Abbey, you will see that his feat of solving these problems is there commemorated by an allegorical scene, carved in white marble, in which little cherubs are represented as engaged in weighing the stars with steelyards. The faculty of weighing the stars is of as much consequence to an astronomer in the pursuit of his vocation as the use of scales is to a grocer. It may be added that the operations of the natural philosopher in this, as in a thousand other particulars, not only extend the limits of general knowledge in various directions, but if the truth were known, have, in many cases, nearly as close and material a bearing on our everyday interests and necessities as the proceedings of the worthies who supply us with tea and sugar.

As to the second question which was proposed just now, namely, "What does the Earth weigh?" the answer, in one sense, is "nothing." For we have seen that the weight of anything means the force with which it is attracted towards the centre of the Earth. If this definition were to be taken as holding good for all circumstances, the Earth could not be said to weigh anything at all, since it cannot, of course, attract itself. But it attracts other heavenly bodies, and in this sense its weight is considerable. The number of tons at which it would scale has been computed, and is represented, when given arithmetically, by a long train of figures. Human faculties of conception are soon defeated when they encounter large magnitudes, so that a numerical statement in the present case would convey no real meaning to your minds. It would be but an expression, bewildering perhaps, but void of import for our finite

powers of apprehension. Nor is any one but an astronomer concerned to know what the precise amount of the weight in question is. But we are all vitally interested in the maintenance of the exact *status quo* of the gravity, whatever it may be, of our Earth. For were it to increase or diminish in the smallest degree, the balance of the forces which keep the mechanism of the universe in motion, and preserve the exquisite smoothness and precision of its working, would be instantly upset, and there would be a general crash and ruin throughout Creation. Such an occurrence would prove a source of discomposure and annoyance to many persons, and would cause an inconvenient dislocation of arrangements.

The law which regulates the effect of gravity has been already mentioned, but it may be as well to recall it. Stated in very general terms it is as follows. The force which the attraction of gravity exerts is in direct proportion to the mass of the attracting body and to its nearness to the body which is attracted. Both the two characteristics which have just been stated as marking the action of gravity may be more fully enunciated in the following manner. Every particle of matter attracts and is attracted by every other particle of matter with a force inversely proportioned to the squares of their distances from one another. Hence you see (to take something very familiar as an illustration) it follows that a pound of tea taken up in a balloon must become lighter and lighter as it gets farther from the Earth, the attraction of the latter upon it becoming feebler and feebler with the length of the distance through which it operates.

An estimate of the attraction which is exercised by the Earth's gravity at any given distance from the surface of the globe may be very easily made, because its power, at that surface, can be roughly appraised in a moment by actual and simple experiment. Hence we readily get a fair starting-point for calculation. The force which the Earth's gravity exerts, say, at this spot where we are assembled, if it were to be tested by a well-known apparatus, called "Attwood's machine," would be found to be just sufficient to draw any and every object, of whatever kind it may be, through a space of 15 feet in one second.

This power is curtailed in practice by the resistance of the air, which varies with the form and constitution of every object which is exposed to its action. If the multitude of tiny atoms which in the aggregate constitute the substance of any given object are closely packed, the gravitating power of the whole body, being, as it is, nothing more nor less than the sum of the impulses by which the particles which compose the mass are animated, becomes condensed, in effect, into a small focus, and only a correspondingly limited surface is afforded upon which the resistance of the air can operate. A furled umbrella would drop more quickly than if it were extended parachute-fashion, and the *Times*, if squeezed up into a paper ball, would make an earlier arrival at the floor than it would do if it were to be let fall as an expanded sheet. The Earth's power, therefore, of occasioning by its gravity a movement of 15 feet in a second, at its surface, is to be taken to mean a capability of producing this effect in vacuo, that is to say in a field of

action from which the air with its retarding influence has been excluded.

Now the point whence the Earth's attraction is exercised may be taken, as we have seen, to be its centre of gravity, which in this particular case is as nearly as possible coincident with the middle of its figure. This central point, the innermost recess of the core of the big orange on which we live, is, as you know, somewhere about 4,000 miles from each and every point on the surface of the globe. The attractive power of the Earth's gravity amounts, as hence appears, to a force endued with sufficient vigour to pull any of the objects which are about us, or ourselves, whether slim or corpulent, through a distance of 15 feet in one second. In other words, such is the measure of its strength when acting at the distance which has been mentioned from its seat of power.

I have not dwelt thus persistently upon the subject of gravity without abundant justification, or, indeed, without clear necessity, since anyone who did not know something of the mode in which the force in question acts could not possibly understand even such simple affairs as the toys which we have lately passed under review, or a single one of ten thousand things which constantly surround us in our every-day life; much less, of course, could even the most elementary conception be acquired of the first rudiments of astronomy, of which everybody of intelligence should have at least some idea.

In concluding this subject, let me beg you to notice the particular language which was designedly employed when it was said that you should understand "some-

thing of the mode in which gravity acts." We can note and estimate the effect which the attraction of gravity produces, but what the force is in itself, or, indeed, for the matter of that, what any force is, are secrets which no man living can reveal to you. It was stated at the outset of this lecture that any examination of even the humblest toys leads straight up to some of the highest and most difficult problems in natural philosophy: we have in this tumbler a proof of that assertion. Any of you who can reveal to the world what gravity is will instantly take rank with Newton, and the greatest philosophers who have ever lived. If, therefore, you desire to make a short cut to a glorious immortality of fame, an eligible opportunity for so doing offers itself to anyone who will give a really complete explanation of the toy before us.

Let me take this opportunity, while we pause for a moment before making a transition to fresh ground, of commending the judicious and agreeable practice of introducing, as is sometimes done, a musical interlude into the midst of a lecture. The tedium of the whole proceeding is rendered a little less oppressive if its continuity is thus broken. A dissertation on toys would lend itself with exceptional aptitude to such an arrangement, since the matters over which it ranges form, as it were, but a loose confederation of subjects gathered, for the time being, under one titular head; and in traversing the series it is often found that members of it which happen to stand next to one another are in no necessary contiguity. The openings thus afforded for intervals of relaxation seem to invite

musical episodes as a relief from the monotony of the speaker's voice.

On a recent occasion when a lecture was to be given at a certain place in the country, the expediency of imparting variety to the coming entertainment was duly felt, but no local resources for the purpose being available, a musical box was borrowed from a neighbouring Parish. At the first favourable break in the lecturer's discourse, the instrument was duly wound up, and set going, but as it was, as has been stated, a stranger in the Parish, a knowledge of the proper manipulation of its arrangements had not been acquired. The consequence was that it played "Cheer, boys, cheer" over and over again, and nothing else, and could not be stopped. This performance, after it had continued for half an hour or so, was considered to partake of sameness; and all the welcome symptoms of voluntary cessation which from time to time appeared and were eagerly hailed, proving unhappily to be merely preludes to renewed outbursts of the same tune, given with fresh and fiendish energy, the dreadful instrument was at length borne forth to another room. There, in tones subdued by distance, but still audible, it continued, with the same "damnable iteration," to pour forth its one odious song throughout the evening.



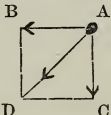
CHAPTER IV.

WE now come to a very large and interesting class of toys which all work upon simple mechanical principles. When you understand their springs of conduct, you will find that you also comprehend, perhaps for the first time, or at any rate better, probably, than you ever did before, the action of numerous implements and machines which are constantly before your eyes, and with whose services your convenience and enjoyment of life is largely and intimately connected. The toys in question are such, for example, as bats and balls, shuttlecocks, kites, arrows, and flying tops. Among the contrivances which ply their various tasks under mechanical conditions which these toys, for the purposes of comparison and necessary illustration, will lead us to examine, are windmills and watermills, ships' sails, the screws of screwsteamers, ventilators, smoke-jacks, and others.

Now there is one, and only one, very simple and elementary item of information which must be bought at the price of a little attention before you can under-

stand any mechanical toy or implement. When you have once secured this, you will find that you hold in your hand the key to the comprehension of all sorts of phenomena which are now locked up from your insight in the dim cabinet of mystery.

Suppose you have a weight, like this, for example, which is borrowed from the kitchen scales, and is very convenient for our present purpose, as it is furnished with a ring at the top whereto we can attach a string. And suppose that you pull that string with sufficient force to draw the weight, what happens? The weight, of course, has no alternative but to follow the string. It does not require a Newton to establish that much. But now suppose that you have two strings, and that you pull both at the same time in some more or less diverging, but not precisely opposite directions, what does the weight do? It cannot obey both, since to do so would be to go two ways at once, so it follows neither, but takes an intermediate course between them. We are thus led towards a particular conclusion which we may regard as a general law applicable to all similar cases, and which will be best understood if it be set forth in black and white by a diagram.

Suppose, then, A  to be a weight acted upon by two different forces, such as were exerted just now by the strings, one of which endeavours to draw it along the line AB, and the other along the line AC. The weight cannot comply with the solicitations of both these forces at the same time, so, as we have already found by actual experiment, it pursues an intervening track

such as $A D$. Can we discover what the exact length and direction of $A D$ will be? We can, in the following manner.

Suppose the two forces which are conceived as acting upon A to be severally represented both in power and direction by two lines such as $A B$ and $A C$. If the lines are to represent the forces properly, and the forces are equal, then they must be drawn of equal length, whatever that may be. If the forces be not equal, then the lines must be so drawn as that their mutual relation in respect of length shall accurately reflect the comparative strengths of the forces. Thus, suppose $A B$ to be a force of 4 lbs, that is to say of such a power as would suffice to support a weight of 4 lbs, and prevent it from falling to the ground; or strong enough, when acting vertically, to press down a scale with as much effect as if it were itself a kitchen weight of that denomination. And suppose $A C$ to be a force of which a weight of 2 lbs would similarly be the equivalent. Then, if we wish to bring these forces from the regions of imaginative conception down upon paper, so as to have them represented in something like a visible personality, and within conditions under which we can more readily subject them to the judgment of our perceptions, we may draw them on whatever scale may happen to be the most convenient, provided only that their relative powers and directions are faithfully symbolized in the manner which has been prescribed.

In the present case, if $A B$ and $A C$ be the two forces, and $A B$ double $A C$, the line $A B$ may be an inch, or a yard, or a mile, or anything else in length, provided only

that it is twice $\angle C$. We have thus got a pair of lines forming an angle  or corner like this. The acute-ness or obtuse-ness of this angle, that is to say its degree of sharpness or bluntness of point, will be, of course, a true exponent of the precise extent of divergence of the forces which our diagram has brought upon paper. Turn this open figure into a closed one by drawing lines respectively parallel to AB and AC . Then the oblong figure $ABCD$ is what is called a "parallelogram."

"Parallelogram" is rather a solid mouthful when spoken, and has a formidable sound, as if it belonged to some awkward and intractable puzzle which only a mathematician could attempt to tackle. But its terrors, like those of a scarecrow, are all in pretence, for it is in reality the very simplest thing possible. A parallelogram merely means a four-sided figure whose opposite sides are parallel to one another. Under this definition we may get four-sided figures of very varied and multitudinous shapes. Squares, oblongs, and diamonds on cards, are all examples of parallelograms. Since any and every four-sided figure which we can invent and draw will be a parallelogram, if only its opposite sides be parallel to one another, the name of such devices must be legion. To return to the particular parallelogram with which we first started.

A line such as AD joining either pair of its opposite corners is called a "diagonal." We now come to the precise thing which is essential to remember, which is as follows. If you have two forces represented by

lines such as these AB and AC , acting on a body at A , and strong enough to move it, the body, as you know, will not follow the direction of either force exclusively, but will take an intermediate track. You can predict exactly what this course will be by drawing BD parallel to AC , and DC to AB , so as to complete the parallelogram $ABCD$, and then linking the points A and D by a line which will be a diagonal of this parallelogram, and which will be found to be the track which the body at A , when acted on by the forces AB and AC , will actually follow.

We have now put two forces together, and seen the result of so doing in what is called the composition or putting together of forces. If you can put any two given forces together, and exhibit the result of their combination, you can manifestly pick any single one to pieces, and show what its parentage either is, or may be. Clearly this is so, but to make it doubly plain, let us revert for one moment to our parallelogram of forces.

Suppose any given line to represent the force which you wish to dissect. Draw any parallelogram you please which has this given line for its diagonal. Then the line in question, as being that diagonal, will represent the effect of either of the two pairs of forces which may be respectively supposed to act at its opposite extremities, personated, as they each are, by two contiguous sides of the parallelogram. Consequently, it is only to put the same statement the other way up, or rather, indeed, simply to repeat it, to say that since the line is equivalent to either couple of forces, they on their part represent it just as much as it does them.

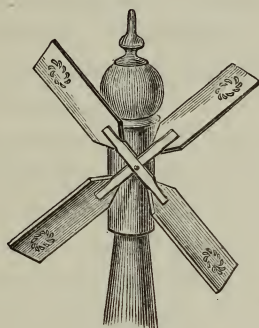
We have thus, as you see, shown how to pick any given force to pieces, and reveal what its parentage is, or might be. Any force will be found, of course, to be the possible offspring of innumerable other pairs of forces, since parallelograms of endless multitudes of shapes can be drawn. Each member, also, of these pairs might similarly be referred to any number of origins.

Having glanced at the main preliminary which is of essential necessity to be understood before the action of any forces can be investigated, we may proceed to note its practical bearing on a variety of things of every day life which may have appeared to be very simple, but which, as some of you will probably come to admit, may be advantageously looked into rather more closely than hitherto.

As a first illustration of this, suppose we take a windmill, as being one of the biggest, most prominent, and most familiar features on the face of the country. What makes the sails go round? The answer, in one sense, is not far to seek, namely, the wind. No doubt; but how does it produce its effect? It can hardly be said to blow the sails round, since its current is against the plane in which they revolve, that is to say, at right angles to the direction in which they move, so that it actually contributes no direct propulsion at all. For from whatever quarter the breeze may come, the mill, as everybody knows, always turns its face flat and full to it, as a sunflower does to the sun.

There is another circumstance which everybody who has a pair of eyes must have noticed, and which would of itself suffice to show that it is not the direct action

of the wind which moves the sail. The fact in question is that the sails often go round a good deal quicker than the wind which is blowing on them is travelling. One does not usually see a cart going faster than the horse which draws it, and similarly, if the wind simply twirled the sails by propelling them round their axle-tree, it could not drive them at the rate of twenty miles an hour while it was itself doing only ten.

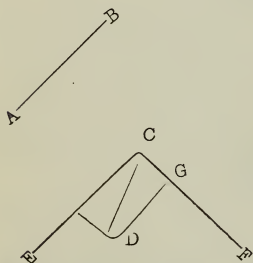


What really takes place is far less simple. Although the windmill faces the wind, the sails taken separately do not stand flat towards it, but obliquely. We will consider what the behaviour of any individual sail must be under such circumstances, and whatever may be found to be true for one will be no less so, of course, for all.

If the sail be flat to the wind, the only tendency which the latter can have with reference to it must simply be to push it straight backwards, but not to move it in any other direction. All the wildest and most impetuous hurricanes which ever escaped from the cave of Æolus might blow till they cracked their

cheeks, but they neither could nor would impart to it any motion at all unless it were to be that of bodily transference from its existing situation to some spot in its rear. They might succeed in tearing it, or in upsetting the windmill, but they would not supply the power to grind a single thimbleful of corn.

The sails, as has been already said, are severally set obliquely to the wind, so that it strikes each of them aslant. What comes of the encounter of the wind and sail under these conditions? Some idea of the answer will be best worked out in the first instance on paper.



Suppose AB to be the sail with its axle at A , and DC to represent the force of the wind striking it, as the Americans say, slantindicularly. What power has DC to make AB turn round A ? To possess any such capability DC must contain some ingredient in its composition acting at a right angle upon AB which will be in the direction FC . Let us pick the force DC to pieces, and compel the particular element of which we are in search to disclose itself, if it has any existence. We can do this in a moment by means of our parallelogram of forces. The parallelogram to be employed must, as you know, have the particular force which we seek to dissect for its diagonal. With this object we draw a line from C at right angles to AB , such as CF , and then another line from C , such as CE , parallel to AB . These lines may be drawn of any length, it does not signify what, because they will be cut down to their proper extent by the process of completing the parallelo-

gram of which they are to form two of the sides. Complete the figure accordingly, drawing from D one line parallel to CE , which will meet CF at a point which we may call G , and another line parallel to CG meeting CE at a point which may be marked as H . Then $DGCH$ is a parallelogram, and DC is a diagonal of it. The effect, therefore, of a force represented by DC will be equivalent to the joint action of two others such as are impersonated by HC and GC .

Now a force such as HC could have no effect whatever upon AB . For HC was, as you remember, expressly and designedly drawn parallel to AB , and a force moving across, but not in any degree against, a flat surface, which is the present case, can have no tendency whatever to move it. As far as the miller's requirements are concerned, it must be quite valueless. The force HC , therefore, may be disregarded, since with reference to the actual conditions of the problem with which we have to deal it is in fact a nonentity, and we find ourselves landed on the conclusion that the effect of DC upon AB is identically the same as that of GC . You will observe that a stronger force when exerted obliquely, as is the case here, has, as would naturally be expected, no more potency for achieving any given result than one which is weaker, but in the same proportion more direct. We can determine in a moment what the precise strength of the force GC is, because we know what DC represents, and that GC bears the same relation to whatever is thus symbolized as the length of the line GC does to that of DC . The appraisalment therefore of the power of GC becomes a simple matter of measurement. We thus, as you see, ascer-

tain in a moment what we set ourselves just now to elicit, namely, what effort a blast such as DC , blowing obliquely upon a sail AB , would exert towards making it revolve.

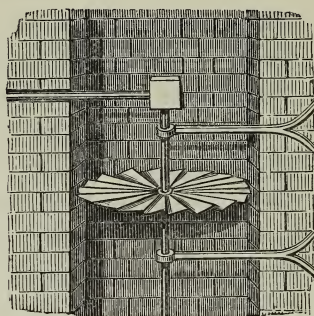
In introducing just now the question of what the effect of the wind upon a sail set obliquely to it would be, I used the expression that "some idea of the answer may be made out on paper." It was not by any means meant that a complete and exact solution of the problem could not be readily obtained by pen and paper. But the actual computation would be too intricate a process for a mixed assembly of people to go comfortably along with, for the following reason. The length of a sail, of course, might be accurately given, according to scale, on the plane, that is to say on the surface, of the paper on which it was drawn, and so could the breadth be, but the direction of the wind would be necessarily perpendicular to the face of the diagram, and could not, therefore, be represented at all on the same sheet, unless by expedients which would unavoidably render the demonstration inconveniently complex. The sort of way in which the precise action of the wind upon the sail may be analyzed upon paper has been already indicated, so that anyone who may care to do so should be able, when at home and at leisure, to investigate the whole business without further assistance than has now been provided.

Now the principle of the windmill, that is to say the contrivance whereby for all sorts of mechanical purposes we convert the force of the wind, which of inherent necessity must be exerted solely along the straight line of its own direction, into a source of circular movement

at right angles to that course, is seen in operation in a great multiplicity of examples. A windmill itself displays the principle in question as applied in two forms. The sails are set and driven in the manner which has been partially sketched, but behind them there is always to be seen, as no one can have failed to notice, sometimes aloft, and projecting outwards from the crown of the building, and at other times surmounting a circular travelling stage which runs on rails round its foot, what looks like a juvenile windmill, and is called a "wind-vane." Its office, as is easily discernible on observation, is that of turning the millcap, that is to say the part of the structure which carries the sails, in such a manner as to keep their faces to the wind, a duty which it discharges by setting, as it revolves, certain cogged wheels in motion. Its own adjustment is such that it always presents its general figure edgewise to the breeze, because in this position, besides actively working the apparatus with which it is connected by rotation round its own axis, it also, by behaving as though it were the vane of a weathercock, gains an increased capacity for its duty of maintaining the sails in their proper attitude. It is, as anyone may see, another version of the very thing which, when playing a part in a different sphere, is called a smokejack.

A smokejack is a windmill as well as a windvane, but with shorter, broader, and more numerous sails, which are employed for the following reason. If the surroundings of the site where a windmill is to be placed are such as to render a tall building admissible, it will be expedient to build one of full stature, so that big sails may be employed, since the longer these are, up to a

certain point, the better. For instance, take any given windmill to be furnished with 4 sails, and that each of them is 30 feet long and but one foot broad. Then the



whole spread of sail computed in square feet will be 30 multiplied by 4, or 120 feet. Say that another windmill is fitted with 6 sails, each 20 feet long, and 1 foot broad. The whole extent of sail which this latter can spread will be 20 multiplied by 6, or 120, that is to say, the superficial area of canvas will be the same in both cases. But the second mill will not have nearly so much power as the first. For each sail is, mechanically speaking, a lever, and a force, such as is in the case before us the strength of the wind, when acting on a weight here taking the form of the resistance on the part of the axle which is to be turned, is exerted with proportionately greater effect through a longer arm than through a shorter one. "Long" and "strong" being convertible terms when used of the arms of a lever in the sense just referred to, 6 sails must possess less efficacy than belongs to 4 in which latter a similar amount of wind-catching surface is drawn out to a greater longitudinal

extent. If, therefore, the height of a mill is, as is expressed in the vulgar tongue of the Servants' Hall, "no object," that is to say, if a high structure, which will permit long sails to revolve clear of the ground, is allowed by the conditions of the locality where it is to stand, so much the better.

The length of the sails must still be kept within a certain limit which is imposed on them by the strength of materials and by other considerations which need not be specified here. But there are, of course, many circumstances under which it would be inconvenient or impracticable to employ sails of full length, and in all such cases their want of this dimension and consequent lack of the efficiency which would have been derived from more advantageous leverage, must be compensated for, as far as possible, by increasing their number and breadth. Hence the particular form of the windvane, which is that also of the smokejack.

Smokejacks are rarely used nowadays, but they were till lately so common that most people must have seen such things. A working model of the main basis of a smokejack may be roughly made in a few seconds by slicing a circular disc of metal into several divisions by cuts made from near the centre to the outside edge. A small area in the middle is left untouched, whereby the disc still keeps together as a whole, and which also serves as a stage which is placed horizontally, and so adjusted as to poise with an even balance upon the tip of a pointed support, so that the whole disc on receiving any impulse is free to rotate with unrestricted ease and freedom. Each of the broad rays of metal which have been formed by the divergent cuts is now

bent a little, after the fashion of the sail of a windmill, so as to present an oblique surface to a current of air flowing against the face of the disc. The instrument thus prepared is now supposed to be set in and across a chimney. The draught upwards, formed by the continuous ascent of hot air from the fire below, acts like a blast upon the vanes of the smokejack, and twists them, and it, round. The motion hence generated is utilized, through the intervention of suitable tackle, for turning a spit. The throat of a chimney would not admit of the employment of long sails, so that motive power is obtained by an apparatus of more compendious dimensions.



Similar considerations govern the construction of the little spinning discs which are sometimes placed over lamps to prevent the smoke from mounting in a direct column, and thus blacking the ceiling. The stream of hot air from the chimney of a lamp is strong, but concentrated within a boundary which is shaped like an upright cylinder, and is defined with tolerable sharpness. A disc, therefore, of greater diameter than the circle which would be given by a horizontal section

of this stream would be proportionately ineffective, since it would have an exterior marginal band of more or less breadth which would constitute a merely passive weight to be carried round at the expense of the energy of motion of the parts within the range of the current of the hot fountain.

Windvanes, (or whatever their proper name may be, when they are doing duty on shipboard,) are to be found afloat, for they are sometimes employed to work the pumps of leaky ships, which they do, with the intervention of cranks, very serviceably. In a case like this any machine in the shape of a windmill would necessarily be altogether inadmissible, since its long arms would be in perpetual conflict with the rigging and the crew. The wheel ventilators, also, which are fixed in window panes are, obviously enough, in principle, and almost in form, merely windmills or smokejacks doing duty in another sphere. Their object corresponds with that of the discs applied to lamps of which we spoke just now, and is that of modifying the impetuosity of the stream of cold air which enters a room, and breaking and scattering its current, so that it may not by a too direct inrush assume the tormenting and deadly character of a draught.

In London, at the very core of the heart of the City, a windvane is one of the most conspicuous objects, perched aloft over the Eastern end of the roof of the Exchange. By the intervention of suitable mechanism it notifies on a dial in Lloyd's Rooms just below, which are the headquarters of those whose business is connected with marine insurances, every variation in the wind as it occurs, the state and prospects of the weather

being, of course, a matter which closely concerns the interests both of shipowners and underwriters.

I have dwelt rather persistently on the nature of the motive power in windmills and other mechanical contrivances of the same order, because as soon as this has been once thoroughly grasped the understanding of a host of toys becomes at once a bit of property in actual possession. That this is so may be shown by examples.

If you go from here to London by train on a day so perfectly calm that there is not even a breath of air stirring, and if, when you are travelling at full speed, you put your head out of window, is the air still motionless? In one sense it is, because the circumstance of your going to London, whatever interest the fact may possess for yourself, does not affect the weather. The air, therefore, continues to be just as tranquil, as far as the world at large is concerned, as it was when you started, but with regard to yourself and the train an actual hurricane is blowing against you and it. You thus find by experience what, indeed, would have been clear enough without proof, that the result is the same, as far as the action of air upon anything is concerned, whether the object in question stands motionless in a high wind, or itself passes rapidly through a still atmosphere. So that if you could put a windmill on the top of the railway carriage, and front it towards the engine, as soon as the train got under way, the sails would be set in motion also. And the faster the speed of the train became, the stronger would be the draught of passing air, and the greater the rapidity with which the sails would turn. A boy who runs with his kite when there

is not enough wind to raise it, acts, of course, upon the principle of creating by this expedient an artificial blast.

Here you come upon the reason why a shuttlecock spins as it flies. Its feathers are placed obliquely, so that the wind exerts the same sort of action on them as it does on the sails of a windmill, and turns the shuttlecock round. You saw why a windmill placed with the surfaces of its sails flat to the wind would not act. Nor, of course, would a shuttlecock spin, if its sails, that is to say its feathers, were not arranged so as to stand aslant to the virtual current of air which flows against them. If they are so twisted as to be no longer oblique, the shuttlecock drops lifelessly, with no motion beyond that of mere falling.

The same is the case with an arrow. The feathers of an arrow are not placed in a line with its length, or parallel to it, but diagonally across the shaft. Hence the result of the factitious blast upon them which their rapid flight through the air creates is to make the arrow spin round an axis which is the central line of its length. Noone, probably, can have imagined that the feathers of an arrow help it to fly, in the sense of aiding its impetus. On the contrary, they necessarily undermine its energy of progression, and act as a drag upon its speed, but this disadvantage is more than counterbalanced by the greater regularity of flight which is induced by the revolution round the axis, so that the shaft can be impelled more true to its mark. Similarly, the shuttlecock, though its alertness in rising and falling is in some degree subdued, which happens to be all the better, by the moderating influence of its

feathers, is far more steady in its proceedings than it would be if it did not spin. Depend upon it that William Tell would never have been so rash as to attempt to shoot an apple from his son's head with an arrow having no other motion than that imparted to it by the bowstring.

There is more than one reason why an arrow, or other projectile, travels in a better ordered course for having a movement of revolution at the same time with that of transmission. We shall find a more convenient opportunity later on of discussing one of the two main causes of the effect in question; the other may be taken in hand and disposed of at once. It is this. No arrow can be made so completely symmetrical, so accurately balanced, so perfectly smooth in surface, and with its feathers so evenly adjusted, but that it carries in its person some little irregularity or other, which, if permitted to work upon it, as a disturbing agency, throughout the whole course of its flight, would eventually succeed in compelling it to deviate more or less to one side or the other from the straight line leading towards its proper goal. Even in the case of an ideal arrow faultlessly made, and that, too, of materials of such uniform substance that it would balance with mathematical accuracy about its axis, still it might very probably receive during the short instant which would elapse after it left the string, and before it got clear of the bow and the shooter's hands, a touch or push from some slight prominence or inequality on one of the surfaces over which it would have to pass, which would impair the precision of its aim. It would be impossible to preclude altogether

the intervention of disturbing agencies of this kind, inasmuch as they are often too small to be dealt with or detected, and they are communicable from a variety of sources external to the arrow itself.

Now any want of balance or other circumstance which is adverse to the accomplishment of a steady and smooth trajectory, as it is called, that is to say the path which is followed by a missile between its point of departure and the conclusion of its errand, is, as far as possible, rendered of none effect by the spinning. For thereby the element of irregularity, whatever it may be, is brought to exert its power in opposite directions, alternately, in rapid succession, so that it annihilates of itself its own effect. It is for the reasons which have been explained that in the game of cup and ball the player makes the ball spin preparatory to attempting his stroke. To land the ball fairly on the spike demands great exactitude of manipulation, and this is much promoted by the steadiness which the spinning imparts.

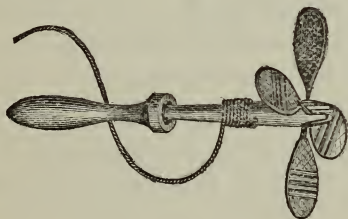
Bullets and cannon balls are rifled on the same principle. In the case of missiles of this description, feathers, of course, could not be employed for imparting the desired rotation. The object is attained, as you probably know, either by cutting the inner surface of the barrel into ridges, not running in straight lines in the direction of its length, but winding round it, or else by scooping two or more parallel grooves, similarly curved, for the reception of a belt or studs projecting from the surface of the ball. The missile is constrained to follow the course which the ridges or grooves impose upon it, and thus emerges from the muzzle imbued

with the rotatory motion which it has acquired within the barrel.

The result which is brought about by a lateral pull of weight, that is to say, by any excess of the heaviness of one side of the projectile over that of the other, when it is not made to counteract its own influence by spinning, becomes conspicuously manifest in the game of bowls. Each bowl, for the purposes of the game, is designedly so shaped as to have one of its sides to a certain extent bulkier than the other. When first dispatched from the hand of the player, and when its forward motion is therefore young and vigorous, the bowl is pretty nearly altogether the creature of its dominating impulse, and travels a course which deviates perhaps but little from the rectilinear track along which it was started. This line of projection must necessarily have been a perfectly straight one, as will more fully appear presently when we come to discuss another subject which lies but a short distance before us. The initial liveliness of movement, however, soon begins to sober down, as it gets tamed and worn by friction, and by other agencies which undermine its vitality; and the bias, as it is called, that is to say the influence of the overplus of weight which the bowl carries, so to speak, in one of its two side pockets, comes into play with an effect which was at first imperceptible but now becomes manifest. The lateral deflection grows more and more marked as the energy of progress declines; the path which is travelled rapidly shrinks from a broad sweep into a narrowing, and eventually sharp curve, till at last the bowl comes to a standstill very much after the familiar fashion in which a dog gets to rest by wheeling round and round

in a sort of spiral coil, till he makes a final turn so contracted as to be almost within the length of his own tail. A plate or basin trundled along the floor behaves in a like manner and for similar reasons.

We will now turn to two toys which act, speaking generally, on precisely the same mechanical terms as windmills, and smokejacks, and the rest of the family of contrivances of which we have just spoken, in which, as has been seen, a revolving motion is produced by air acting on sails, or sheets of metal, disposed obliquely to its course. The principle involved has been already dwelt upon so much that we may pass over very rapidly instances of its employment similar to those which have been already considered.



One of the toys in question which we have not yet dealt with is a flying top, as it seems to be called at the shops where such things are sold. It is, as you see, an affair which looks like a four-winged butterfly, or a cross between some insect of that kind, and a windmill, and it is furnished with a shank and other arrangements which need not be more particularly described, so that it can be wound up like a common top. When this is done and the string is pulled, the top is, as will be found, fired with an impulse to start somewhither. It strives to

leave the handle, or to burrow down into it, according as it is made to spin in one direction or the other. The first question which its conduct suggests is that of why it does not spin contentedly where it is, without either trying to rise to the ceiling, or evincing a solicitude to get down to the floor. To understand this, attention must first be directed to what is perhaps the very simplest and most elementary fact in mechanics, and which is expressed by the statement that "Action and Reaction are equal and opposite."

Before examining the proposition which has been just enunciated, let me give you a word of caution against being misled into erroneous conceptions of the terms Action and Reaction. The employment of these words, which treacherously cover fallacious suggestions as to the true nature of the occurrences which they profess to describe, is a misfortune, but we cannot alter or dispense with them. If you consider for a moment the notions which the words are calculated to convey, and what the real truth of the matter is in the position of affairs as to which they are used, you will be proof against any misleading tendencies which they might otherwise exert.

That Action and Reaction are equal and opposite means that whenever any object or body strikes, presses, or pulls another, the force which is exerted by either of the parties to the encounter is met at any and every point where they are in collision or contact by a direct and corresponding resistance.

I hold in my hand a book. It weighs, say, a pound. I put in action in supporting it a force which may be defined as one of a lb., since the measure of its strength

is accurately thus indexed, and the weight of the book exerts a reaction, pressing downwards on my hand with a like degree of energy. A horse drawing a cart, to borrow an illustration given by Sir Isaac Newton, is pulled back by the traces to the precise extent of the power which he employs. A schoolmaster gives a boy a box on the ear. The boy's ear returns, and at once, the compliment to the schoolmaster's hand without either interest on, or discount from, the degree of violence, whatever it may have been, to which it has been itself subjected. If it were to be urged that this cannot be so because the ear receives a painful blow, while the hand does not suffer in any corresponding manner, such an argument would be based on confused notions of the occurrence. The ear and the hand strike one another with precisely equal force, but the sensations which are excited by the collision are more acutely felt by the former because it is the more tender of the two. If I push against a wall, the wall gives me, in return, a shove which is just as decided as my own.

If you were to controvert the assertion that when a body which is in motion strikes another which is at rest, the aggressor gets as hard a knock as the victim of its onslaught, you would find yourselves committed to all sorts of absurdities. You would have, for example, to admit that a bullet which is fired at an iron target, and hits it, commits self-destruction when it is beaten flat by the stroke. The bullet is knocked so completely out of shape that its most intimate friends would now fail to recognise it. Did it batter itself into the likeness of a sixpence by some

suicidal act, or else how was its present abject condition induced? The iron plate against which it was shot positively and actually struck in its turn, and the result was such as would naturally ensue from a blow from such a source, when virtually wielded as a hammer with a force equal to the impact of the bullet.

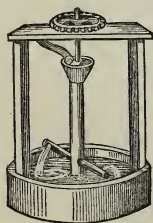
It is expedient to detain the matter which is now under our hands sufficiently long to possess ourselves with a full, clear, and firm apprehension of it, because Reaction, generally speaking, does not get its fair share of recognition. Its operation is apt to be entirely overlooked by those who have not been in the habit of considering mechanical problems, in all of which, of course, it plays a part of prime importance. In a great many cases we set Action going solely for the purpose of creating Reaction, because it is this latter which we wish to call up to do some particular service for us within its own department.

A case in point is that of a rocket. What is it which causes a rocket to leap into the air? To a great extent Reaction. The carcase of a rocket is made of stout cartridge paper rolled into the shape of a hollow tube. The material is light, and at the same time its inner surface will stand contact with a good deal of hot flame for a few moments without being itself consumed. The tube is filled with a mixture of combustible powders of kinds such as will burn vehemently, and produce a torrent of sparks, which are wanted to form the tail. This compound, when set alight, produces a sudden and intense heating, and consequent expansion of the air in the tube exactly as gunpowder does, in a still more vehement and instantaneous manner, in the chamber of a gun. The

dilated air, together with the elastic gas which has been generated by the combustion, not only presses upwards, but rushing in an impetuous stream out of the open end of the tube, thrusts downwards against the atmosphere outside, and carries the rocket in whatever direction its head may be pointed.

In a gun the whole force which the explosion of its charge of powder is capable of generating is called into being, accomplishes its entire life's work, and dies, within the space of one short instant. This force acts, of course, upon the interior of the gun itself, as well as upon the hind-quarters of the shot, and causes the recoil. In the case of a rocket, no sudden spasm of force is aroused, so that there can be no bursting of a barrel, and the inconvenience of a recoil is avoided, since the air, as will be seen, taking the place of the breech, there is nothing to be driven backwards, but the projectile makes its own way by a comparatively gentle, but sustained, push from the rear. It may be mentioned that in Hale's military rockets the backward rush of the gases engendered by the combustion in the tail is so directed as to impart a spinning motion to the projectile, thus giving it the precision of flight which belongs to rifles. The rocket propels itself just as a man punts a boat along a river. The boat represents the firework; the shove given by the puntsman answers to the impulse generated by the stream of hot air arising from the blazing of the combustibles in the rocket's tail, and the bottom of the pond, which returns poke for poke through the oar or pole which is used as the instrument of propulsion, behaves, mechanically speaking, precisely after the fashion of the reacting air.

The revolution of a Catherine wheel is imparted to it by a similar agency, which, by the way, is as old as the Creation. To adduce but one instance out of innumerable illustrations of the fact just stated with which natural history teems, it may be mentioned that the Nautilus is not, as generally supposed, a sailing boat, but a rocket, for its real method of progression is far less picturesque but more practical than that with which it is credited. It does not spread a delicate membrane like the sail of a fairy ship to the breeze, but sucks in and afterwards squirts out backwards a stream of water from a narrow tube which forms a part of its personal arrangements, and thus, in short, punts itself along. Steamboats propelled after the fashion which is exemplified in the nautilus are to be seen upon the Thames. The original source of motion is, of course, the steam engine, which corresponds in this particular with the muscles of the animal, but the immediate instrument whereby progression is actually achieved is a stream of water, which is sucked, or allowed to flow, into a suitable receptacle, and thence discharged through a pipe in a vehement stream in the direction, whatever it may be, opposite to that towards which the boat is intended to go.



Watermills have been constructed on the same principle. The most familiar machine of this particular kind is known as Barker's Mill. The water is admitted from above into a hollow cylinder, poised vertically on a pivot, and escapes thence through holes bored in the sides of tubes projecting horizontally from the base. The jets

which are thus formed generate, for reasons already indicated, forces directly contrary to their own courses. Their combined effect upon the tubes which are, in effect, handles of a windlass, and arms of a lever, is sufficient to make the cylinder spin. The whole contrivance is an expedient for obtaining from a perpendicular fall of water a circular and horizontal motion, such as is capable of direct appliance to the task of grinding. The earliest form of steam engine, commonly known as Hero's, was a machine in which the mainspring of power was obtained through the same principle as that on which the action of a Catherine wheel, or a Barker's Mill, is founded. Turbines, which are also hydraulic engines, give a sufficiently clear indication of the nature of their source of action by their sub-title of "reaction wheels."

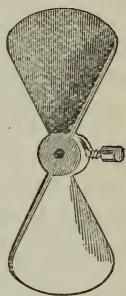
It should be mentioned that in all the contrivances of which we have been speaking during the last few minutes, the whole of the motion with which they are animated when set going is not exclusively referable to the source to which alone for the sake of convenience and simplicity it has been assigned. Their action might, indeed, be regarded in a different view, as follows. The principle of their contrivance is, it might be said, the generation of pressure, and its subsequent relief in one quarter only, that, namely, which is opposite to the direction towards which motion is sought to be produced. The result necessarily ensues of movement due to giving, or yielding, in compliance with the promptings of the unweakened forces which now come to prevail. The explanation, however, which was first propounded is not incorrect as far as it

goes, and it was adopted as being illustrative of reaction as a moving force.

To return now to our flying top. When you make it spin very rapidly, its wings strike the air, which returns their blows with a spirit and effect precisely equal to their own. The pinions are set, and the blows given, slanting, so that the reaction is oblique also. If you seek to know what the effect hence produced on them must be, this can be ascertained in a moment by picking to pieces the forces concerned in the transaction by means of a parallelogram drawn after the recipe which was given just now, for solving problems of this description. It will then be found that the result in question must be to carry the top in one direction or another, according to the manner and attitude in which it has been spun. Conceive that the top had but two wings instead of four. Would it still fly? Judging by analogy it would, because although most insects have four wings, birds have but two. We may assume, therefore, that if we have a two-winged top and point its nose horizontally, that is to say so as to direct its course along a track lying level between the ceiling and the floor, it will fly accordingly. Now imagine it to be linked with the handle from which it is set going, so as to be all of a piece with it. The latter will then be pulled along or pushed backwards, according to the manner in which the top is spun. The toy is now seen to be in fact an exact model in miniature, as far as its principle of action is concerned, of a screw steamer. It is, mechanically speaking, the same thing.

There is just one point on which it may be as well to bestow some notice here. In a ship's screw there

are usually only two "limbs," as they are called, and it is not of itself apparent why windmills should have never less than four sails, while screws have mostly, like some of the rough specimens of these toys, but two. In the case of the toys the explanation is that myriads of them are made to sell wholesale at a good profit for a penny each, and nobody could expect to be able to buy at so low a price the most perfect thing of its kind which could be turned out, but merely the simplest article which will work. In the case of ships' screws the advantage which is generally found in limiting them to two limbs is readily to be accounted for. We cannot diverge into an examination of that matter here, as it does not fall quite within the range of our proper business this evening, and I merely advert to the point of the small number of the limbs in the ordinary marine screw to show that it has not been overlooked.



There is one other subject which ought perhaps to be noticed under the head of screws. A question may occur to some of you as to how it is that screws are used at all for moving ships. It might be thought that since they act obliquely, power must therefore be wasted, the reaction on them which constitutes the forward impulse not being in a line with the course of progress of the vessel. The employment of paddle wheels might thus seem to be more economical of force, because these latter may appear to push straight backwards against the water. The answer is that a paddle wheel is as prodigal as a screw in its waste of

mechanical energy. Examine, for instance, the case of any one of the flat boards, or "floats," as they are commonly called, which are ranged within the outside rim of such a wheel. If you investigate its precise course of conduct you will perceive how much fruitless labour it squanders. Now whatever any individual float does in this respect, all its fellows on the same paddle wheel must do too, since they are all just alike, are all similarly placed, and all behave in the same manner, so that anything which may be found to be true for one will necessarily apply to all. Thus if the futile expenditure of power which is to be laid to the account of any one of them be multiplied by the number of the whole set, the sum of the waste on the part of the entire paddle wheel will have been ascertained. To come now to particulars.

When the float first comes into contact with the water, it strikes it pretty nearly flat, and presses it almost straight downwards. The resistance which it evokes on the part of the water is a reaction which is a force in the opposite direction, that is to say almost entirely upwards. This latter does next to nothing towards propelling the vessel forwards, but simply and vainly tends to lift it. As the float gets buried deeper and deeper by the revolution of the wheel, its action assumes more and more a horizontal direction, such as is needed for pushing the water backwards, and the reaction upon it goes through corresponding changes towards a force of direct propulsion. When the float arrives at its lowest position, that is to say when it is vertical, it then at last acquires for the first time a capacity for exerting action which is altogether calculated to

serve its intended purposes. But at this juncture it is already half through its whole period of immersion, during which alone it can do any work at all. Nor does it retain the advantage of the position in question for a single entire moment, for with even the smallest possible degree of further revolution of the wheel, the outside edge of the float is instantly brought a little upwards, and purely horizontal action is thereupon lost at once. Much of the float's force is thenceforwards vainly spent in lifting a quantity of water, which, by its reaction and weight, tends only to depress the ship.

The action of a paddle wheel is thus attended by a serious waste of power lavished idly in scooping, as it were, a great hole in the sea, but this is not the only disadvantage which is incident to it. A second main objection to which it is open is one with which our present inquiries have no concern, but it will be more satisfactory to make a short divergence to it so as to wipe up the subject of paddle wheels with a nearer approach to completeness.

The violent downward battering on the water in front, and the laborious upheaval behind, cause the machinery to strain and vibrate in an uncomfortable and injurious manner. An attempt is sometimes made in the case of large ships to mitigate these inconveniences by what are called feathering paddle wheels in which the floats shift their attitude in such a manner as that they keep always vertical; but the friction of the machinery which is required for procuring this continued fresh adjustment is so great as to make extravagant demands on the engine-power on its own separate

account. Another device, therefore, is frequently adopted which aims at relieving, though it does not attempt to exclude, the mischief complained of, and which consists in using what may be called composite paddle wheels. Each of such wheels is made up of two or three narrow ones joined together at their sides. The floats of these several wheels are so arranged as not to be in straight lines with their neighbours. It will be perceived at once that the effect of this contrivance is to render the action upon the water of the composite wheel, as a whole, less intermittent, and thus more equable and gentle than is the case with the simpler form of construction. The blows and lifts on the part of the floats are, no doubt, in their aggregate mechanical effect, alike for both cases, the total area of surface which encounters the water being the same ; the shocks and strains, however, are mitigated by subdivision, that is, through being broken up, so that they become components of a closer-packed series of collisions, which are more numerous indeed, but individually of less violence.

The end which is sought by the employment of composite paddle wheels is occasionally pursued by other contrivances, such, for example, as that of breaking up the broad surface of the float into stages by substituting for the single board, of which in its plainest form it consists, several comparatively narrow strips of wood, arranged after the manner of steps in a staircase. The abruptness of encounter with the water is thus mitigated, as the whole shock of impact is reduced into the form of a series of what may be termed little slaps, instead of heavy bangs, and the total effect of these is distributed over a certain space of time. But all these

matters are far off our proper track, to which we should at once return.

A paddle wheel is identical in form with the wheel of an undershot watermill. Moreover, if you consider the action of the stream upon such a wheel when doing duty in connexion with a mill, you will notice that it is subject to just the same disadvantages in respect of waste of power as is the case when it is officiating as the propeller of a ship. It appears, therefore, that as a windmill, mechanically speaking, is the counterpart of a steamer which is driven by a screw, an undershot watermill corresponds in the same manner with a ship which is impelled by paddles. The flight of stairs wrapped round a cylinder which is the main feature of a treadmill, is identical, mechanically speaking, with an overshot waterwheel.

Our disquisition on screws and paddles would form a natural introduction to an inquiry into the conditions of the propulsion of boats by means of sails and oars. And it would be quite proper to glance at this topic as a branch of our task of this evening because boats are among the most common and popular toys. But since the main use of a lecture, as the author of "The correlation of the physical forces" says, (my recollection of his precise words is imperfect, but I am not sure that he does not put the proposition so broadly as to say the "only" use of a lecture,) is to incite and to help people to investigate for themselves, the subject of oars and sails, being rather a large one, had better be remitted to the category of those which we will put aside to be looked into by any of you who may have been led to feel some interest in the matters with which we have been busy.

If what has been said about windmills and other cognate machines has not been altogether in vain, whatever secrets may be latent in the operation of sails and oars will be quite easily caused to reveal themselves.

A good deal of discussion has taken place of late years on the subject of vivisection, that is to say on the question whether it is right to allow experiments to be made on the bodies of living animals for the advancement of the knowledge of physiology; to inflict, in short, a certain limited degree of pain or injury on certain creatures for the purpose of gaining such knowledge as will, among other advantages, enable us to reduce the aggregate of suffering which would otherwise be the lot, not of humanity only, but of the whole community of sentient beings. Whatever opinion may be held on the points in dispute, nobody, at any rate, can possibly object to our vivisectioning a live force, and thus discovering of what it is, or may be, made of, and how the various sinews which go to form its composition are likely to affect objects with which they are put in relation. Since you must now be taken to be expert practitioners in mechanical surgery of this innocent kind, you may profitably subject a wind of any specified power to dissection, and ascertain the force which it is calculated to exert, when blowing from any given quarter, upon a sail of any stated dimensions, and stretched in any defined position and attitude. You may further determine how the sail, thus wrought upon, will tend to produce motion, and of what kind and amount in any particular ship to which it is attached.

Before taking leave of boats it may be pointed out that an angler who uses artificial bait will perceive an

illustration of the action of a ship's screw in the spinning fish with which he captures pike and trout. The means by which the peculiar movement which is requisite is imparted to the bait has been sufficiently indicated. For it has been shown that if a windmill were to be carried on a train going at speed the sails would be put in revolution by encountering a virtual gale of wind. And for similar reasons it is plain that a marine screw, if it were to be wholly abandoned to the action of the water upon it, would revolve, if the ship to which it belonged were moored in a flowing stream, or were to sail, or be towed, over a still lake. In fact, the commonest method of ascertaining the speed of a vessel is by noting the number of revolutions made within a given time by an instrument of the character of a screw, dragged astern, and turning freely in compliance with the action of the water which in effect, under such circumstances, streams against it.

This last mentioned contrivance is identical in the nature of its springs of conduct with an artificial minnow. The counterfeit fish is fitted with metal appendages having the semblances of a tail and of fins standing out obliquely to its length, so that when drawn against the water it spins rapidly. This, of course, is just what a real fish does not do, for such a movement could not fail to make him extremely giddy, and addle what little modicum of brains he may possess. But through the blurring effect of "persistence of vision" in the eye of a jack or trout, the true nature of the bait's movement is indiscernible, as is also, for the same reason, the deceptive personality of the minnow itself, which often, indeed, is not even made, otherwise than in its general sort of

outline, in the likeness of a fish at all. Similarly, the hooks with which the bait is profusely armed, if they are visible at all, are but dimly so, presenting only the appearance of an indistinct steel-coloured halo enveloping the body of the object to which they are attached, so that their real character is effectually masked. The spinning contributes also something towards the successful mimicry of nature by making the gestures of the bait more composed and fishlike than they would otherwise be, since the axis of rotation, as was noticed in the case of an arrow, and as will appear more fully bye and bye, has a tendency to maintain itself unaltered.

It is under such deluding conditions as these, therefore, that a hungry pike or trout catches a glimpse of a fleeting object, which is not clearly determinate to sight, but which seems to be of about the size, shape, and brightness of the minnows or gudgeons which are his usual prey, and which swims to all appearance after the orthodox fashion of such creatures. Ignorant, therefore, of the wiles of anglers, he makes his snap at the bait, and gets caught. It would hardly perhaps afford much consolation to the poor wretch, as he lies gasping upon the bank, to be told that he has unwittingly had the honour of illustrating in his own person, as by a working diagram, the practical effect of some of the scientific principles which we have lately been considering.



CHAPTER V.

IN thinking over the list of toys to be spoken of this evening, I should hardly, if the selection had rested with my own uninstructed judgment, have included pumps among them, and still less fire engines. Such things as these would have been taken to belong essentially to the domain of serious life and business, and to be concerned with the sober interests and necessities of grown up people only. But on looking in at the windows of a great number of toyshops for the purpose of learning what were really the principal features of their contents, I found, rather to my surprise, that not only squirts, but small working hydraulic machines of the kinds which have been mentioned, were everywhere to be found in great abundance, so that they preferred a claim, which could not fairly be disallowed, to take rank among the very commonest and most favourite playthings of all. Such being the case, it was clear that any disquisition on toys from which these particular ones were to be omitted would be as wanting in completeness as a novel without a heroine.

The reason of the warm popularity of toys which

have to do with water is readily to be descried in the keen delight which children find in making a mess. So universal is this juvenile passion that there is no impropriety in conceiving that even the most august personages, such as the Queen when she was a little girl, and the Archbishop of Canterbury when he was a little boy, must have revelled in making mud pies, or at any rate must have longed to enjoy that pastime, if the natural tendencies of children were healthily developed in them. A squirt has hence a claim to full examination as an especially popular favourite; moreover a real, and not merely fancied, understanding of it is the necessary half-way house on the road towards a knowledge of other toys and contrivances which are based on similar principles, but whose construction is not quite so simple.

There is a creature called a marine ascidian, better known by its popular name of a sea-squirt, though its conformation is more nearly akin to that of a pair of bellows, which belongs in about equal degrees to both the animal and vegetable persuasions. According to Mr. Darwin, marine ascidians possess the same kind of direct ancestral relationship to humanity as squirts do to fire engines. We are all of us pronounced to be ascidians, only that we are gifted with a more elaborate complexity of bodily structure than belonged to our remote forefathers; a condition which we have gradually acquired in the course of a long series of ages and descents. It behoves us therefore to view all branches of the great family which bears the name of Squirt with proper respect.

A squirt, as everybody knows, is charged by immersing its spout in water, and then drawing out its

handle. As this is done, the water enters, nor will it run out again, whatever may be the position in which the instrument be held, until it is forcibly ejected by pressure brought to bear upon it through the handle. The first point which arises for consideration when these facts have been noticed is that the water first runs upwards, and then refuses to flow down through an open pipe though not restrained from so doing by any visible obstacle. Behaviour like this is out of conformity with the usual conduct of all liquids, which, being amenable to the attraction of gravity, never mount a hill of their own accord, and always course down an incline when the road is open. The phenomenon is to be accounted for in a very simple manner.

The body of the squirt is a tube of smooth and uniform bore, and it is furnished with what is called a piston, that is to say a plug, fitting its interior so closely as not to allow air to pass between its outside edge and the surface with which it is in contact, but yet not so tightly jammed as to prevent it from sliding comfortably up and down. The piston is moved by a rod, working through a tolerably loose collar at the closed end of the tube. This covering of one end of the tube is no essential part of the constitution of a squirt. The object of the arrangement is merely one of convenience, and it is twofold; first, that of preventing the piston from being dragged right out of the tube by too long a stroke, and secondly, that of keeping the rod, while in action, in its proper posture, which should always, of



course, be parallel to the surface within which it works, taken lengthwise.

When the piston is pulled back, it drags before it all the air which was inside the tube, and conducts it out through the collar. Thereupon if the passage through the nose of the squirt be free, other air enters by it, and supplies the place of that which has been withdrawn. The entering air follows close on the heels of that which retires. Why it thus comes in seems nowadays to be so obvious that it sounds like trifling to propose to talk about it at all, and yet it is only quite lately, comparatively speaking, that the true nature of the proceeding has been recognised. The so-called explanation formerly given was that the outside air thus enters because, as it was quaintly and mysteriously expressed, "Nature abhors a vacuum." A vacuum, as you know, means a space empty of everything, air included, and the assumption which was made, and which was quite gratuitous, and unsupported either by proof or likelihood, was that Nature, in a spirit of blind caprice, is animated by some peculiar antipathy of her own, of which no reasonable account can be given, to the existence of a void.

To render such a theory as this capable of holding any water at all, the shadowy sort of abstraction which we call Nature, meaning by the term the settled order or law of creation, had to be endued in thought with an actual personality and with small mental weaknesses, since vagaries of sentiment, such as that of disliking empty places, could not, without a violent spasm of imaginative fancy, have been conceived to be felt by a mere dry state of facts relating to the Universe. It was

held, however, that whenever any space becomes empty, the substance, whatever it may be, which happens at the moment to be closest to the spot in question, hurries in to fill the void, unless it be restrained from so doing either by its own rigidity of figure, or by some other impediment. This sham of an explanation explained nothing, and was doubly inadmissible. It implied, as will be seen, that inanimate things are nevertheless amenable to a sort of moral compulsion, for it alleged that, in deference to a supposed edict of Nature, they, passive though they must always be in the hands of forces which they have no power either to generate or control, still, in one particular case only, take action of themselves under the influence of a special motive. Or, if the doctrine was that the movement in question was to be taken as somehow or other originated by Nature, this theory was wholly bereft of any possible meaning whatsoever. For the term "Nature," when thus used, merely made a vague suggestion of some unknown agent, without pretending to define the machinery by which its ends were brought about.

The true account of the matter of course is that it is altogether a mere question of simple physical forces whose mode of operation is perfectly clear. It has thus nothing to do with any erratic predilections attributable to an imaginary old lady, called Dame Nature. A right view of the case was accidentally brought about by the following occurrence. A pump had been erected in the palace of a certain Grand Duke of Florence, and although the job had been done by the Court plumber, and the apparatus was unexceptionably good of its kind, the water obstinately, and, as was thought,

unconscionably, declined to rise to the spout, which was rather more than 32 feet above the cistern. Galileo, who was living close by, was applied to to explain the enigma of the failure. He was then a very old man; and although he seems to have scented the real secret of the difficulty, he had probably become too much past work to put his surmises to the test of experiment. He therefore contented himself with merely throwing out a hint on the subject, as a clue to be followed up by his pupil Torricelli. The latter in due time elucidated the whole thing clearly enough, and showed the weight of the atmosphere to be the real beginning, middle, and end of the whole mystery.

It has been already stated that if a vacuum is created inside the squirt by pulling out the piston, air immediately enters from the outside through the nose, if that passage be free, to supply the place of that which has been withdrawn. This is a consequence of two facts, the first of which is that air, as Torricelli discovered, has weight, and the second, that fluids press equally in all directions. The latter proposition requires a little expansion in order to make it thoroughly clear and familiar to the mind.

A fluid may be defined to be a material body, or substance, whose parts are separable, and moveable among one another by any force, however small. Do not confound the meanings of the words "fluid" and "liquid" by treating them as altogether convertible terms. Air and water are both fluids, but the latter is also a liquid, which the former, except in poetical language, which has a licence to be vague, is not. The opposite to a fluid is not a "solid," but a "rigid."

body, that is to say an object, or substance, whose component parts are incapable of altering their relative positions. A force applied to any point of a rigid body is transmitted in one direction only. A force applied to any point of a volume of fluid is transmitted equally, that is to say with undiminished vigour, to each and every particle of the whole mass, that is to say, in all directions. The foregoing statement is made in very rough and general terms only, and would require limiting and qualification before it could properly be taken as the basis of reasoning on all matters relating to the mechanical properties of fluids. It will, however, serve our purposes of this moment, as being true in the broad sense in which only we shall employ it.

It will be a repetition of the same statement, rather than a deduction from it, to say, further, that fluids press equally in all directions. The atmosphere, therefore, gravitating downwards from the sky by its own weight, presses, as being a fluid it is bound to do, in all directions, including upwards, at the aperture of a squirt's nose, whatever may be the posture in which the instrument is held. It is kept at bay at that point by the equal and contrary pressure of the air already inside the tube, which, on its part, similarly derives its power of resistance from the weight of the atmosphere above. For this operates upon the piston on the quarter where the rod joins it, and through it on the fluid beyond with which the underside is in contact. Whenever, by the raising of the piston, the force which supports the resistance of the air inside the nose of the squirt is withdrawn and nullified, the balance of contending energies is upset, and the victorious power outside brings in

some of the external atmosphere, which thus follows close on the heels of that which is in retreat. Consider this history of what has been supposed to have occurred as necessarily repeating itself at the conjuncture when the nose of the squirt is immersed in water, and the reason why the tube fills with liquid when the piston is retracted becomes at once apparent.

The squirt is popularly said to "suck." Beware of this expression, which, as tending to convey a misleading notion of what takes place, is a treacherous one. Neither the squirt, when it fills with water, nor a person who sucks an orange, acts directly upon the liquid which enters the tube or mouth, as the case may be. In either process the real character of the operation is to relieve an inclosed spot of the surface of the liquid which is to be exhausted from the weight of the atmosphere, which therefore acts afterwards, all round, only, and not upon, the place in question. Its pressure, thus applied, does the practical work which is required by impelling the liquid in the direction where alone its passage encounters no resistance, that is to say towards the vacuum which the mouth, or piston, has created. To suck up any fluid, therefore, in the sense of drawing it by the direct action of any machinery, or of any combination of mouth and breath, is a process which, although it sounds as if it were the very simplest operation which could possibly be performed—so simple, indeed, that even an infant is thought to be necessarily obliged to execute it before it can obtain its very first taste of its mother's milk, is yet a feat which, if the popular understanding and interpretation of the term were to

be accepted, has never yet been, and never can be, accomplished.

The squirt is now full of liquid. Water is heavier than air, and therefore if the piston were absent, the squirt would not keep full when its nose was held downwards, but the posture of affairs which has to be considered is as follows. The air, as has been said, weighs or leans upon or against every point which it can reach either by the way of direct contact, or by transmitting its pressure through any substance or thing, whether rigid or fluid, which will yield to its impulse, or convey this onwards. It thus pushes through the open nose of the squirt against the under surface of the water inside, but it is precluded from acting on the upper side of the mass of liquid by the interposition of the piston. The piston is not amenable to downward pressure at the present moment, since it is held up by the hand, or maintained where it is by the agency of another extraneous power, namely that of friction, of which more anon. There being, therefore, nothing to counteract the sustaining action of the air but the weight of the water, which is here a force of inferior energy, the cylindrical column of which it consists being but a short one, the necessary consequence is that the liquid, like a good citizen "obedient to the higher powers," does not avail itself of the exit which the open nose of the squirt appears to offer.

Precisely the same thing happens in the case of our old friend, or, as, perhaps, it might more properly be called, our ancient enemy, the shower bath. At the top of the institution in question is a reservoir, closed above, but having its cover furnished with a valve, that is to say

a little door, opening at the pull of a string. The bottom of the cistern is pierced with a multitude of little holes, as in the rose of a watering pot, to which the shower bath bears a close relationship both in its personal appearance and its ways. Until the valve is opened the water is sustained in the cistern by the pressure of the outside air, which as yet can act upwards only. When the patient inside the curtains summons courage to pull the string, and thus open the valve, he thereby admits air to the upper surface of the water in the cistern. The upward and downward pressure of air below and above now counterbalance and mutually destroy one another's effect, and the water being thus practically freed from the controlling action of any atmospheric force, becomes obedient solely to gravity, and descends by its own weight.

To give one more illustration of the same matter. Fill a tumbler with water quite up to its brim. Lay a flat piece of smooth paper on the surface of the liquid, and then having turned the tumbler as quickly and as steadily as possible topsy-turvy, place it with its rim downwards on a plate. If this manœuvre be executed with sufficient decision and address, the water does not escape. It is certainly not the paper, however, as I have actually heard contended, which sustains the liquid, a bit more than the car of a balloon, loaded as it is with ballast, and with a miscellaneous freight of weighty articles besides, lifts the balloon from which it is itself suspended. The employment, indeed, of the paper might be dispensed with if the feat were to be performed with extreme dexterity. The sustaining agency is solely the pressure of the air. This gains

access to the exposed portion, exclusively, of the surface of the liquid when the tumbler is turned upside down, inasmuch as the rest is protected by the glass. Thus the only force to be taken into account is one of upward direction, and it is strong enough, for this is shown by the experiment itself, to bear up a column of water of the tumbler's depth. The paper is of some little use in tending to keep the open surface of the liquid unruffled, and horizontal throughout every portion of its whole extent, maintaining for it, as it were, a flat face, so that the supporting power applies itself with a greater evenness of distribution, and consequently with a better unity of effect, to the entire area. The delicate conditions of equilibrium thus gain a more favourable chance of preservation. The whole story of the pressure of air, as exerted everywhither within its reach, and as thus tending to leave no vacuum at any spot to which it can gain access, or into which it can propel something else, is, as you see, simplicity itself.

We have now to inquire how it is that air presses so heavily as it does on all bodies which are exposed to its action. It will be necessary to dwell fully on this subject at whatever risk of being tedious, because unless the power which the weight of the air constitutes, and the effects which it brings about, are thoroughly grasped in conception, not even a thing of such elementary simplicity as a squirt, and still less a pump, or a multitude of common toys and implements, can be really understood. "Trifles light as air" is a saying which contains a certain degree of truth, but which is liable to create misapprehension, because the weight of the atmosphere is in some senses enormous.

First of all what is air? It is a mixture of two gases, oxygen and nitrogen, united, but not brought together in equal proportions, since there is a much larger volume of the latter than of the former, but not so much by weight in the compound which represents these two constituents of the union in their married state. Now although oxygen, as being a gas, must, according to the popular idea of such substances, be necessarily something very light, still, it is the fact that many members of the family to which it belongs, are, on the contrary, extremely heavy. Carbonic acid gas, for instance, may be poured from one vessel into another just as if it were water. Oxygen may well be called a heavy substance since it constitutes about half of the material of soils, rocks, and minerals, and a large proportion of the weight of a prize ox, or of a mammoth gooseberry, is due to its presence. In the case of the ox, as much, perhaps, as about three quarters of his weight may be credited to the oxygen which he bears about his person.

Now although oxygen is largely diluted with nitrogen, which is a much lighter element, still it retains its own inherent quality of weightiness, and imports this into the compound of gases which is called air. Nitrogen, too, although it is no doubt extremely light, still has some weight, and therefore any very great bulk of it would, in the mass, scale up to a high figure. Feathers are not individually heavy, but a legion of them would weigh something, and a featherbed as big as Mont Blanc would be a really ponderous article.

Now the air rests upon the surface of the whole earth like an enormous featherbed about fifty miles thick. We

have some grounds for supposing that the atmosphere does not extend to much more than the distance upwards over our heads which has been named, unless in a very attenuated condition, in which it would more properly pass under some other designation, such as that of ether, since it could then hardly preserve the characteristic qualities of the substance which is so familiar to our perceptions as air. We believe, however, that the globe's overcoat of air, properly so called, has no less a thickness than that which has been mentioned. One reason for this opinion is that some years ago a meteor, which was computed to be, at the moment, as much as fifty miles from the earth, was heard to explode. But since sound is, in fact, nothing but ripples of air in motion, the explosion which has been referred to must have been mute if the atmosphere had not extended as far as the spot where it took place. The duration of twilight, also, seems to show, from certain conclusions which are to be drawn from the particular phenomena of refraction which then occur, that the cloud in which the earth, like a deity in the *Æneid*, is enshrined, is of about the depth which has been already stated. But whatever may be the weight of the earth's atmospheric envelope, the heaviness with which it presses on any given spot can be measured as easily as if it were that of a packet of tea. It may interest you to learn, and to be enabled to realise in vivid conception, what kind of amount the actual weight of the atmosphere attains at this place where we are assembled.

To form an idea of its magnitude, suppose that the windows of this room were filled up with brickwork, and the walls carried up to a height of thirty-two feet

from the floor. And imagine that the large tank into which the room would thus, in effect, have been converted were to be filled up to its top with water. There would then, you know, be a very heavy weight of water on the floor as a whole. But this weight would be no more and no less than that with which the air is pressing on it, and on us, at this moment. In other words, a block of water thirty-two feet deep weighs, roughly speaking, as much as a tower of air about fifty miles high, if the area of the base is the same for each.

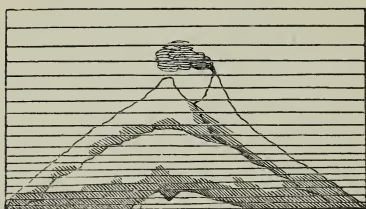
Now quicksilver is much heavier than water. If this room were, as has been conceived, made into a tank, and you were to let off the water, and flood it with quicksilver instead, the metallic tide, when it had risen to a height of about thirty inches, would attain to the same weight as that of the water which preceded it, or that of the tall column of air whose base now, in fact, rests upon the floor. The amount of the whole weights of the three several masses of fluid could, of course, be stated offhand, if the dimensions of the base which is common to all of them were ascertained, since it would be the product of 15 lbs. multiplied by the total number of square inches which go to the whole area of the floor. This would be so, because the pressure of the atmosphere, though it varies with the weather, and with sundry other conditions, may be taken as being, under ordinary circumstances, about 15 lbs. to the square inch. Cut a piece of card precisely one inch square, and take 15 lbs. worth of kitchen weights. Lift the latter, and you will find that 15 lbs. means something, more especially if you drop the weights on your foot, but this, and no less, is the

burden of air which every portion no bigger than the bit of card, of the surface of everything about us has to bear.

Our bodies, of course, have no immunity, more than anything else, from this pressure, and since we have a great many square inches of surface on our skins, we have to stand altogether a pretty good squeeze. In the case of a grown person of the average size, the atmospheric pressure which he or she has to sustain amounts to the enormous weight of about 14 tons. We are entirely unconscious of it, because, since fluids have the property of pressing equally in all directions, if you hold out your hand, although there is a weight of air of, say, perhaps, about 150 lbs., on its back, this is counteracted by the equal and opposite atmospheric force which heaves upwards against the palm. Nor do we feel the clasp of the atmosphere which hugs us in so tight an embrace all round, because this is directly opposed by the no less powerful expansive tendency which is exerted by the elastic fluids contained within the body. If these elastic fluids were to cease to act, we should be squashed as flat as pancakes in an instant. On the other hand, if the external pressure were to be withdrawn, or much diminished, very serious results would follow. We may step aside from the line of our strict course to notice one or two of such consequences in some slight detail, since they are curious and interesting.

The weight of the air, as need not be said, is greatest close to the surface of the earth, and becomes less and less as ascent is made from that level. Hence, also, the whole mass of atmosphere becomes gradually more

and more attenuated in texture as its higher limit is approached. To elucidate this clearly we will take, as before, the case of feathers as an example, since they are the accredited and established representatives of



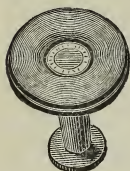
light substances. If, then, you had a pile of them, heaped as high as the tip of the spire of Salisbury Cathedral, the upper ones would be much less closely packed than those below, because the weight of the former would press down the latter, and condense these into a smaller space than they would have occupied if they had been allowed to lie lightly on one another. Hence it is that when people go up in a balloon, or ascend a high mountain, the pressure of the air on the outside of their bodies diminishes.

Now we each of us, as you are aware, carry about within ourselves a sort of forcing pump, which acts of its own accord, and which never relaxes its industry for even a single moment until we die. This untiring labourer is the heart. It works very much after the fashion of a pair of bellows. If a pair of bellows were to be filled with a liquid, and the handles were to be then pressed together, the fluid contents would be forced out through the spout. The heart, expanding of its own accord, that is to say without any visible source of action, though its motion is, no doubt, imparted to it from the

nervous centres, fills itself with liquid. When full, it contracts, again, to all appearance, automatically, and thus forces the blood with which it is charged through the pipes which are called arteries, by constantly repeated jets, or beats, which we know as a series by the name of the pulse. The tide is driven on beyond the arteries into a labyrinth of tiny hair-like veins called capillaries, which permeate what may be termed the outermost suburbs environing our bodies in all directions. These capillaries are of such delicate structure that they possess but little intrinsic firmness of their own, and they are only enabled by the aid of the constricting action with which the atmosphere supports them to control the tide whose impetuosity tries the strength of their texture. When, therefore, this aid is withdrawn, or materially reduced, they get overcharged, and sometimes burst.

It is necessary to dwell, almost interminably as you may think, on the subject of the pressure which air exerts by its weight, because a very clear idea of the matter is a quite indispensable preliminary, not only to the understanding of a squirt, but to that, also, of countless other toys and implements. For example, the very simplest and rudest of all playthings, the suckers, consisting of bits of wetted leather, with strings attached to them, with which little boys about the streets raise stones, derive their working power from the pressure of air. Everybody must have seen such a sucker as has been mentioned in its plebeian form. Identically the same thing appears in a more civilised and elaborate shape, artistically constructed of india rubber and brass, and useful as a self-fixing peg, which may be caused to attach

itself firmly to a window-pane or any other smooth and flat surface without other support than that of the air.



The india rubber is of its own natural constitution yielding and flexible, and accommodates its face to that of the glass, when applied to it under a little pressure.

In the sucker, the leather is wetted, and being thus rendered soft, like a plaster, is spread upon a stone.

Do not suppose that the leather is wetted for the purpose of making it sticky. If it were dry and stiff, it would be hard and unaccommodating, and could not be brought into sufficiently close contact with the stone; air would then contrive to insinuate itself between the two. In the case of metallic or other substances, the hardness and imperviousness of whose texture is not amenable to moisture, oiling or greasing is resorted to for the purpose of filling up the passages left between two areas of contact through which, if not thus blockaded, air would make its way. Not even the flattest and smoothest plate of metal or glass is, as you will remark, a true mathematical plane, so that the tiny hills and dales which occur throughout its whole extent form so many obstacles to an intimate matrimonial coalition with any other surface. The resistance to complete approach is, of course, doubled when two faces which are thus similarly conditioned, are laid together.

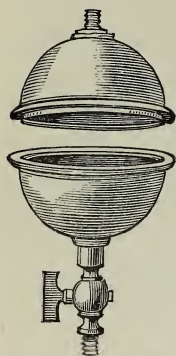
In the case of the leather the intervention of the water, partly by its softening influence, and partly by filling up, like the oil, any interstices which occur, produces an hermetical, that is to say an airproof, conjunction. This being so, whenever the centre of the sucker is pulled

a little apart from the stone by means of the string, a vacuum is formed under it. The pressure of the air on the surrounding margin of leather suffices to keep it tightly attached to the stone, so that they may both be raised together by the string without parting company. In the case of the peg referred to just now, the pad of india rubber is placed close against the glass or whatever else it may be, to which it is to cling, and its centre is then drawn back by means of a screw. The air of course behaves as it did to the stone, and squeezes the rim of the pad hard against the surface to which it is applied.

Nature (which, as being a vague term, is not always a desirable one to use, but is sometimes convenient for describing created things as they are in fact developed and moulded by the surroundings in which they have been set to play their parts), has furnished many animals, and notably the families of limpets, barnacles, and such like creatures, with all the requisite tackle for converting themselves, whenever occasion requires, into living suckers. They are thus enabled, as is necessary for their self-preservation and enjoyment, to stick to hard, smooth, and slippery rocks with an obstinacy which checkmates the efforts of most of their many enemies who seek to detach them.

The effect of the pressure of air is effectively shown by a practical demonstration. The tackle required for the purpose consists of an air pump, and of a hollow iron globe which parts at its waist into two concave hemispheres or cups fitting one another at their edges, which are closely in contact indeed, but without any union whatever other than that of mere

apposition, so that they will separate again without the least resistance. One of these is pierced by a pipe,



through which, when the cups are united, the air which they inclose can be exhausted by means of the air pump. The pipe is furnished with a stopcock by which the entry of air from the outside can be prevented when that within the cups has been withdrawn, so that the globe may still remain empty when disconnected from the pump. It will now be found that the hemispheres, when a vacuum has

been formed within them, cannot, owing to the converging forces which the atmospheric pressure directs upon them all round, be parted without the exercise of considerable violence. Their mutual and pertinacious embrace is in no degree due to any adhesion of their lips, since on turning the tap of the stopcock, they are found to come asunder without the least reluctance. These cups are familiarly known as the "Magdeburg hemispheres," as they were invented by a burgomaster of that city.

One is reminded by them of the operation of cupping, a mode of bloodletting now but infrequently resorted to, in which the initial stage of the proceedings is to withdraw some of the air from under a cup applied by its rim to the skin of the patient round the spot where an incision is to be made. The blood which is in the surrounding neighbourhood is driven towards the inclosure, since it is subjected to pressure on all sides except in that quarter. When it has joined that which

is already on the spot the swollen tide spouts freely from the exit which is opened to it by a slight incision made for the purpose ; just as the winds, according to Virgil's description, escaping from the cave of *Æolus*, "*qua data porta ruunt.*" A trifling cut has thus, through the contrivance which has been described, the effect of producing a copious flow, which is the object sought to be attained. Anyone who has a curiosity to experience the sensation which attends the preliminary stage of cupping may do so by burning a scrap of paper in a tumbler, and as the flame goes out, pressing the palm of the hand closely over the rim of the glass. The glass will be found to convert itself into a sucker, and will resist detachment from the hand. The reason of this is that part of the air in the glass was used up by combustion, and the rest was temporarily expanded by heat so as to fill a greater space than that which it now, when cool, occupies. A partial vacuum has thus been formed under the hand.

A similar experiment to that made with the Magdeburg hemispheres might be shown, in which the air pump would be dispensed with, by substituting for the cups flat slabs of glass or metal pressed close together along one whole surface of each of them. It is not easy to obtain plates of any kind which can in strictness be considered as otherwise than ruggedly smooth and mountainously flat, the production of surfaces even approximately true in respect of level being a feat of manufacturing skill of extreme difficulty, to the accomplishment of which Sir Joseph Whitworth has devoted the highest possible skill and pains. But on pressing together plates which for ordinary purposes may be

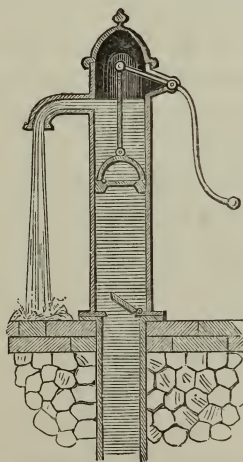
regarded as flat, so that they are brought into close contiguity over the whole area of the sides which are in mutual contact, a soft cushion, suggesting to the sense of touch the impression of jelly, or thick but soft oil, will be found to be interposed between them, over which they will readily glide with a sort of floating motion. This is due to the interposition between them of a layer or film of air, the atmosphere having a disposition to cling with much obstinacy to the surface of everything to which it has once gained access. On squeezing out this fluid cushion by further pressure, the plates are brought to a closer junction, and the weight of the external atmosphere now reaching and acting on their exposed surfaces only, they cannot be dragged asunder without a violent pull.

This experiment is not so satisfactory for its purpose as that with the cups, since the pressure of the air is not always the only force which is concerned with bringing about the adhesion of two surfaces in contact. Many substances are imbued with a tendency, which varies in strength with the nature of the material which is concerned, but which is sometimes, as in the case of lead, a powerful one, to coalesce with other portions of similar matter, when pieces of them are laid together so closely as to bring the constituent particles of two surfaces which are thus united, into very intimate conjunction.

The pressure of the atmosphere may be pretty well appraised by trying one's own strength against it. Close a pair of kitchen bellows by pasting an airtight patch over the valve at the side, and stuff up the nose with a cork, so that no air can enter. If you now try to expand them, then the resistance with which the air

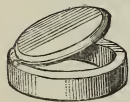
will meet your endeavours to do so will prove a tough antagonist.

Now that it has been clearly and fully borne in upon your perceptions, as a fact realised in conception, and not as a mere matter of words, that air has considerable weight, a great variety of toys and implements whose construction may hitherto, perhaps, have appeared to involve some puzzling enigma, will be once for all divested of mystery, and the principle of their action will stand confessed. We are at length, therefore, in a position of complete advantage for addressing ourselves to the consideration of engines of a little more complication than squirts, such as pumps, since any power which they might have possessed up to a few minutes ago, to present difficulties, must have been by this time altogether knocked out of them.



The body of a pump is a hollow tube tenanted, as in the squirt, by a piston, with its rod. The "suction"

pipe, as it is called, which descends into the liquid which is to be raised, corresponds with the nose of the squirt when snuffling up water. We may demur to the propriety of terming the pipe a "suction pipe." The inaccuracy of idea conveyed by the name in question has been already adverted to, but in a somewhat cursory manner, and it is so necessary to avoid the confusing notions, utterly fatal to any understanding of the topics which we are upon, to which the employment of the word "suction" is calculated to lead, that it seems to be a duty to reiterate, as shortly as possible, a caution against the fallacy which the term does its best to create and cherish. For "Suction" seems to imply, or suggest, action of some kind or other exerted by the person or thing sucking upon the fluid which is imbibed or inhaled. The pipe, you must not forget, is absolutely passive as far as relates to the water which is to be raised. It is simply and solely the pressure of the external atmosphere, and by nothing in the nature of a draught upwards that the water mounts into, and rises within the body of the pump.



There are two little valves in the anatomy of a pump which a squirt does not possess, one of which is at the point of junction of its body with the suction pipe, and the other in the piston. Both these valves are so hinged as to open upwards only. You may not be aware of the fact, but we all, if constructed on the orthodox lines of human physiology, have in our veins a system of little valves, opening, like those in a pump, only one way. Such a phenomenon, however, need excite no surprise as occurring in the persons of improved

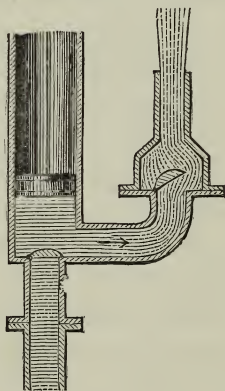
ascidians. The effect of the valves, constituted as they are, is analogous to that of the wicket gates at the entrance of the Zoological Gardens and elsewhere, which compel the streams of arriving and departing visitors to flow, respectively, in prescribed courses.

When water is to be raised, the piston is first pushed down to the bottom of the tube, and subsequently lifted. As it rises, a vacuum, as explained just now, is created below it. Thereupon some of the water in the cistern is forced by the pressure of the atmosphere acting on its exposed surface up through the suction pipe into the body of the pump, which it accordingly fills as the piston ascends. The instalment of it which has been raised thus far cannot run back again into the suction pipe because of the lower valve, which only opens upwards, and thus bars any attempt to pass in the downward direction. Such is stroke the first.

For stroke the second the piston is once more lowered, and as it falls, the water which is in occupation of the body of the pump necessarily pushes its way through the descending valve which opens upwards on demand. As the piston is again raised, the water resting upon it is lifted, not being able to escape downwards, the designed action of the valve forbidding this. As soon as the water which thus mounts in the body of the pump reaches the level of the spout it naturally runs out by that exit, since it is now wholly abandoned to the control of gravity. The history of the first stroke necessarily repeats itself with every succeeding one. The piston rod, as everybody must have seen, for this part of the apparatus is visible enough, is put in motion by a handle of sufficient length to afford a

convenient degree of leverage, and is worked with a crank. Such is the common sucking pump.

If what has been said as to the pressure of the atmosphere for any given area being equal to that of the weight of a column of water about 32 feet high has been understood, it will be seen that a common pump cannot lift to a greater altitude than this, so that the range of its usefulness is strictly limited. If, then, a cistern at the top of a house is to be filled from a well, or water to be poured on the roof of a burning building to extinguish a fire, it would be necessary either to employ a series of sucking pumps, one above the other, which would be absurdly inconvenient, or else the services of a machine possessing capabilities for satisfying the requirements in question must be obtained. Such an implement is found in the force pump. It is just a



little different from the sucking pump, in two or three points, which are the following. First, its piston contains no valve, but is simply a plug, as in a squirt. Also it may be said to have no spout. Instead of this latter

there is a pipe which opens out of the lower part of the body of the pump, and turns in any direction towards which the water is to be propelled. In this pipe is a valve which is so hinged as only to open upwards. Suppose the piston to be at its lowest position. When it is raised, a vacuum is created below it, and the water follows it as it mounts, filling the body of the pump. When the piston descends, the water finding no passage through it, as it does in the case of the suction pump, is driven up the pipe at the side and through the valve therein, which, hung as it is, permits no return. Every valve in a pump is like a certain gate whence "*Vestigia nulla retrorsum.*" Thus, by a continued succession of strokes, causing a like series of instalments of water to climb up through the valves, the fluid can be raised in the pipe as high as may be desired.

Any quantity of water might thus, of course, be lifted to the Cross of St. Paul's from the level of the pavement below, if sufficient power were forthcoming to work the pump. This would be all that could be wanted if St. Paul's were a house, and the requirement were merely that of filling a cistern on the attic floor, but if the building were on fire, and a stream of water were needed for pouring over the dome, the forcing pump, if not equipped with any further appliances than those which have been described, would fall far short of the demands which such an exigency would create. In such a crisis it would be of essential consequence to have available some machine capable of throwing water with great force of propulsion, and in an abundant and sustained tide, to any point, or height. Such an engine presents itself in a forcing pump when

furnished with a trifling and very simple accession to the arrangements by which its work of mere lifting is performed. The additional tackle in question consists merely of a box which a pipe enters but does not completely traverse. The serviceable qualities of the box are entirely due to the elasticity of air, a property which must be fully comprehended before the exact nature of the part which it plays in the instance before us can be understood. Elasticity must first be defined, and when it stands before us represented in terms it may be brought out to view with sharper clearness if light is thrown upon it by a few illustrations.

Elasticity is the quality through which a body which has been bent, extended, or compressed, reassumes its original posture, shape, or volume, as soon as the force by which its arrangement or figure has been temporarily altered ceases to coerce it. Probably all substances in nature have something, however small, of the quality just described. Others possess it in a very high degree, but nothing, so far as we know, is perfectly elastic. A perfectly elastic substance, if the mutual relation of its component particles to one another in point of arrangement, were to be altered by the dilatation or compression of its mass, would, when relieved from the disturbing force, re-establish their original disposition with absolute completeness, and would do so with an energy in no degree inferior to that by which the displacement was effected.

India rubber is a leading example of elasticity, and since a ball of that material is a first favourite among toys, we may take the present opportunity, as being both a legitimate and convenient one, of noticing with

some little particularity of detail the source whence its attractiveness, which consists in its talent for bounding, is derived. When the ball is dropped on the floor, or thrown against a wall, the part of it which strikes the carpet or the bricks, as the case may be, is driven in by the blow. Consequently, the ball loses, for the moment, its symmetrically round figure, and assumes that of a dome bounded in one quarter by a flat base. Immediately, however, that the force of impact has spent itself, and the reaction of the surface on which it was exerted has ceased to squeeze in the ball, the property of india rubber by which it replaces the original boundaries of its mass as often as these are disturbed, is allowed to come into play. Under its influence the flattened portion resumes its convexity, and in so doing, pushes against the surface which it touches. The push, like that of a puntsman, or of a man jumping with a leaping pole, impels the ball smartly from the point of contact, thus causing what is called the rebound.

If a clean elastic ball be gently laid upon a board, or other smooth surface, which is smeared with wet paint, it will be found, when removed, to have brought away with it a tiny spot, only, of the moist colour, thus showing that the contact between itself and the stage on which it rested was confined to a small point only. If the ball be afterwards dropped upon the same surface from a little height above it, or be otherwise brought into more or less sharp collision with it, the area of the spot will be found to extend itself in exact proportion to the energy of impact. This shows by a proof recorded, as it were, in written characters, that the figure

of the ball is locally affected by the blow, and to a degree corresponding with the vigour of the encounter, for otherwise contact could only take place at the infinitely small point where a flat surface and a sphere are capable of touching one another. The shape of the ball must, therefore, it is clear, have been temporarily modified, and lost its character of a perfect sphere. It is also patent at a glance that the original contour of its person has forthwith re-established itself.

Not long ago, in turning over the leaves of a book on elementary natural philosophy, I noticed an error, which is not an uncommon one, in the definition which was given of elasticity. It was stated that gold, and the material of which spiders' webs are formed, are both of them extremely elastic, inasmuch as they can be drawn out into marvellously long threads without breaking. It is true that the substances in question are extensible to a surprising degree. Gold, moreover, admits of being expanded laterally, as it is eminently malleable, that is to say it may be hammered out into plates which are almost inconceivably thin, surpassing in this respect the scanty smear, amounting to hardly more than an unctuous gleam, which feebly represents butter as spread upon slices of workhouse bread. Indeed gold may be made so attenuated as to lose its opacity, and become translucent. But spiders' webs and gold, so far from being elastic, might be taken as typical examples of just the opposite quality. Elasticity was confused in the book referred to with a different thing, namely, ductility, which means a capability of being led out into threads without losing coherence. To justify a claim to the title of elastic it is not enough

that a high degree of extension should be tolerated without breaking. Viscous substances, like honey and tar, may be pulled, or allowed to drop into strings, but when so treated they contentedly acquiesce in, and retain their new condition, since they have no innate disposition to concentrate themselves anew into a compact mass. It should, perhaps, be observed that matter may be partly viscous, and partly elastic. Ice, for example, possesses elasticity in no inconsiderable degree, but it is also viscous, that is to say, under certain conditions, such as that of the pressure of its own weight, it shares with liquids their mechanical aptitude for running downwards through a channel like water.

In view of the erroneous notions as to the true meaning of the word elastic, which, as has been mentioned, are found to exist, and which are promoted by misleading statements made by professed authorities, it may be worth while to point out an instance of a rather different order of the quality in question, namely, that which may be described as the habit of voluntarily resuming an attitude which has been temporarily disturbed by some extraneous force. Glass (not the "toughened," but of the original kind) may be selected as the example now required. When thick, it is brittle and not pliable, that is to say, it will break, but not bend, thus resembling the "*nescia flecti*" spirit of Irish patriotism of which Moore sings in the Irish Melodies. But when spun with threads, or spread out into thin plates, it becomes highly elastic, for these, if bent, or doubled up, will, when the force by which they have been twisted is relaxed, reinstate themselves in

their original condition of straightness with an indomitable alacrity such as is not displayed to the same extent, or with the same pertinacity, by any metallic or other substance. The material which forms the substance of glass is of course just the same, with the same inherent qualities, whatever they may be, whether it be in the form of a block, or of thin plates, or of threads. But the mechanical conditions under which it is bent obviously differ with these several states. Steel, within certain limits, is characteristically and exceptionally elastic, as in the case of the blades of Toledo swords. Nor need it be said that steel in the form of watch-spring is elastic, for so to be is the sole end and purpose of its existence in that capacity.

In the elasticity of air we find yet another, and larger, phase of the quality than those which have been reviewed. The essential nature of elasticity is always, it should not be forgotten, the same, and it is only the particular manner in which it displays itself which varies with circumstances. Susceptibility of compression or extension, and automatic self-readjustment as soon as the stress of the external force which has produced disarrangement permits, constitutes the elasticity of air, glass, and steel, alike, and of everything else. In the bending of a watch-spring the particles of steel on the outside of the curve are, of course, temporarily drawn asunder into situations farther apart from one another than such as they naturally occupy, while the atoms of material on the inside are proportionately squeezed together.

Air has the property of almost unbounded expansibility in all directions, for it penetrates into every

spot to which it can gain access by any adit, however narrow and tortuous, while at the same time it is ready to shrink under compulsion within extremely limited confines. The elasticity of air is, indeed, so dominant a quality of its constitution that any given quantity of our atmosphere cannot be said to have any natural dimensions of its own, but must be taken as accepting and owning such, merely, as are from moment to moment imposed on it by the forces whose combined result determines the amount of extension which it is to possess. It may be too much to say that air is expansible or elastic to an absolutely infinite degree. By extreme dilatation it may perhaps become disintegrated, that is to say, its constituent atoms may eventually lose both their coherence and their tendency to gregarious arrangement, so that having once parted company very widely, they may be unable of themselves, or indisposed, to resume close association. This happens with india rubber, and with watch-spring, when strained beyond a certain point. The nature and degree of the elasticity of air will be best realised by witnessing some practical effect resulting from it. The air-gun will supply such an illustration as is desired.

The stock is a hollow tube of strong iron, closed altogether at its butt end, but fitted in front with a valve opening only inwards. The gun is loaded by forcing an excess of air into this hollow stock, say, a dozen or twenty times as much as would in the natural order of things be there. This is done by means of a simple implement called a condenser which will be explained presently. When the air is pushed in, it cannot get out again by reason of the valve which opens

only inwards, so that the more strenuous the effort made from the inside to open this door, so much the more tightly does it keep shut. When the gun is to be fired, the barrel, which is open at both ends, is screwed on to the stock, so that the bullet, reposing in the breech, is brought close upon the valve which has been mentioned. There is no occasion to describe the precise arrangement of the trigger. It will be enough to say that when pulled it so acts as to throw the little valve open for some fractional part of a second, thus allowing a small instalment of the foremost air which is behind it to escape. The portion thus liberated issues in the form of a sharp puff, and striking full against the hind-quarters of the bullet, propels it from the barrel. The whole proceeding which has been described shows how extremely elastic air is, because, in the first place, it submits to be compressed into a small portion, only, of the space which it had previously occupied, and secondly, it expands again, when permitted to do so, with brisk animation and power.

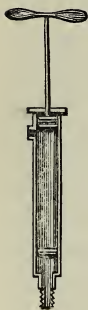
Experience with an air-gun also shows that the elasticity of air increases with its density, and varies with it in direct proportion. The trigger, by a suitable adjustment, may be caused to open the valve to any greater or less degree which may be desired, and it will be found by experiment that a small puff given off from air which has been crammed very tightly into the stock is equal in propelling power to a fuller blast when the intensity of compression has been relieved by one or more discharges.

Many gases resemble air in the capability which they, too, possess of being condensed, and of spontane-

ous expansion. A good example of the qualities in question is presented by soda water. Soda water is made by the compression of a particular gas called carbonic acid gas. This substance is obtainable from many sources, from chalk among others, and by means of strong pressure it is forced into water, which it occupies in the condition of a multitude of tiny bubbles which interpenetrate the body of the liquid. The cork being now driven in, and kept in its place by strings, these take upon themselves the task of maintaining the pressure which has been applied, so that the gas still remains imprisoned, although the particular agency by which it was originally coerced is now suspended. On relaxing the compression, by cutting the strings of the cork so as to allow the force which is acting on its under surface to have its way, the gas, by virtue of its elasticity, expands to what we may for convenience term its natural volume. It is this sudden expansion and escape of gas and air which causes the pop and fiz. Soda water has been called "water with a sneeze in it." We have seen that it might be better defined as "gas with a squeeze in it."

Water has no elasticity at all; at least none worth speaking of, since under a pressure of 15lbs. to the square inch it loses only one 47-millionth part of its volume. If the stock of an air-gun were to be filled with water, fifty steam engines could hardly ram in any more. The receiver might be burst, but the water could not be compelled to retreat into a space materially smaller than that which it is of its own inclination disposed to occupy. It thus presents a marked contrast to air, which is so elastic that enough

of it to discharge ten bullets in succession may easily be packed into the small chamber which is constituted by the hollow gun-stock. This brings us to the sub-



ject of the instrument by which the gun is charged. The condenser, which is merely in principle the same thing as a pair of bellows, is a strong iron tube with a piston fitting it so close as to be airtight. For purposes of convenience and efficiency, the piston, in this case, is made so long in the body that it becomes, in fact, one with its rod, and fits, and fills, the tube like a plug.

When the gun is to be charged, one end of the condenser is screwed to the stock. The piston, having been previously drawn out, is now pushed right home to the end of the tube, driving the air there into the stock, whence, by reason of the valve which was described just now, it cannot get back. On the piston being now pulled out again as far as it will go, air once more fills the tube, entering it through a hole made for this purpose in its side. This second tube-full, like its predecessor, is sent to prison in the stock, and the process is repeated as many times as the strength of the operator permits.

From the severe exertion which a contest with air in forcing it into the stock of an air-gun demands a vivid appreciation is gained of the fact that the atmosphere, though it eludes some of our direct perceptions, is—Hamlet and his “incorporeal air” notwithstanding—a “body.” Steam, it must be admitted, has a distinct material personality of its own, although, like air, it is utterly invisible. That white vapour which is so familiar

to us at almost all times and places, is in reality a fog of minute watery particles caught up and carried by the steam, just as the stream of heated air which ascends from a burning substance bears upwards with it innumerable tiny atoms of unconsumed fuel forming a cloud which is called smoke. But steam, like air, has never been seen by human eyes.

This is the right opportunity, while we are still handling an air-gun, for saying a few words about the same weapon in its more innocent form in which it does duty as a toy, and is then known as a pop-gun. An air-gun would appear from its *modus operandi* to be merely a long and powerful sort of pop-gun. This is partly true. In both cases the pellet, or bullet, or whatever the missile may be, is, no doubt, impelled by the elastic power of air, but this force does not do business under precisely similar conditions in the two implements respectively. In the air-gun, as has been seen, a magazine of compressed air is established in the stock, and allowed to escape in small and sudden gusts. These instalments of captive air leap forth with much vivacity when released from confinement, and expand with an energy which rivals that of exploding gunpowder. In a pop-gun, two pellets are placed, with an interval of space between them, in a hollow tube open at both ends, which they fit so close as to be airtight. When, by means of a stick, the hinder one is pushed towards that which is nearer the muzzle of the pop-gun, the air between the two is compressed, and acts as a strong spring exerting a direct opposition to the thrust of the operator, and striving with equal vigour to force the foremost pellet forwards. This latter is for some time

restrained from stirring by friction, which is the impeding power generated by the close contact of the pellet with the interior surface of the tube. As the hindmost pellet is urged onwards, the inclosed air, in proportion to the increasing degree with which it becomes compressed, acquires an augmented expansive potency, and eventually, overpowering the resistance of friction, dispatches the foremost bullet outwards.

It would hardly be doing the fair thing by elasticity if we were to dismiss it finally from consideration without a more distinct recognition than has yet been expressed of its serviceable character in enabling us to pack up or accumulate stores of mechanical power which may be afterwards drawn upon, or allowed to exert a regulated action of their own, as may best conduce to the performance of any task requiring some sustained motive agency for its accomplishment. A watch supplies a working diagram illustrative of this remark, since the spring, when coiled by winding, takes in in a moment or so a supply of power which, being allowed to expend itself in an orderly, measured, and slow manner, keeps the works going for a long time. The Mont Cenis tunnel through the Alps was bored by adzes driven by compressed air, which resembles an elephant in its two most prominent characteristics of strength and tractability. For the purpose of the work just referred to, stores of force were accumulated, just as in the case of an air-gun, by squeezing air into closed vessels which thus became ever-ready magazines of power at the disposal of the engineer. Elasticity thus used as a mechanical power is in fact a maid of all work, doing in all directions more multifarious and

valuable services to the human community than it would be possible to enumerate.

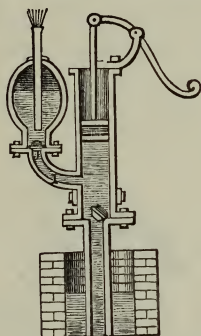
Force may, of course, be stored in other ways than in the Savings-Bank which elasticity keeps open for its safe custody. The weight of a clock, when raised by winding, is endued with a fund of power which may be called "energy of position," that is to say, it is gifted with capabilities for work by the mere possession of the situation which it occupies. Dormant energy of this kind is usually called "potential," to distinguish it from force actually at work, which latter is called "kinetic energy." A reservoir of water upon an eminence is no less truly a reservoir of power, since the fluid possesses in and by its weight a potential energy which it is ready, on demand, to exert. In other words, when it was pumped to its present depository its cistern was filled with energy of gravitation as much as with liquid. Surplus force may be also laid up for future use in a flywheel. In this case the deposit of savings of power does not, it is true, form an investment of capital of a more than transitory kind, but it is one which under various states of circumstances has paramount advantages. Notwithstanding the existence of the contrivances which have been mentioned, and of many others, for the storage of power, the facilities which elasticity supplies for the purpose are so great, and in such constant requisition, that they may be said to be indispensable to the necessities of mankind, as they certainly are to the arrangements of Nature as constituted by the established order of Creation.

A convivial party of thieves was one evening sitting in a public-house, listening to a story which was

being told by one of their number, when some constables entered, one of whom, touching the speaker on the shoulder, intimated to him, in policeman's phrase, that he was "wanted." Being "wanted" by the police usually means, as a consequence, a spell of prison, and in the present case the sequel was a term of penal servitude. On being released, after some years of imprisonment, the convict returned to his ancient haunt at the thieves' public-house where he had been apprehended, and finding some of his old associates there, resumed the thread of his story which had been so rudely interrupted without further preface than "Well, as I was saying." The perpetual digressions from the main high road of this lecture into the byeways which open along its course perhaps render our journey sometimes a little bewildering to you, as you may find a difficulty, such as the thief's audience may be conceived to have felt, in recalling to memory, after a long interval, the exact point whence we diverged. If this discursiveness is to be justified, and I resolutely maintain that it is not only excusable, but right and necessary, it is to be defended on the ground that travellers who visit unknown or unfamiliar districts gain a far more real and thorough acquaintance with the country through which they pass by taking a few steps now and again into the lanes which open off on the right and left of their proper track, and even by wandering into fields clean out of the course which leads to their destination, than is attained by those who, in a strictly methodical, humdrum, and business-like fashion, tramp the highway, not concerning themselves about the country which lies beyond the hedge

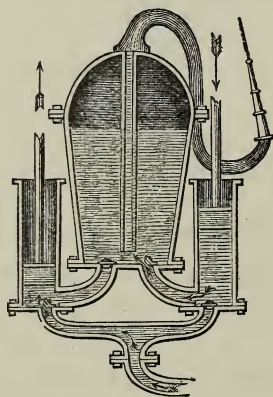
on either side of their path. And now to resume with the thief's "Well, as I was saying" the thread of a topic which was broken off a long way back.

In a common force pump, as has been shown, the water is driven up into a pipe, and this may be as short or as long as circumstances may render convenient. In fire engines it is very short, soon ending in a close chamber or box called the air chamber, furnished with a tube, which enters it through its top, but does not traverse its entire length downwards. We will call



this the exit pipe, because it furnishes an open outlet to the surrounding air. The air chamber may be of any shape: a cylindrical form with a domed top is usually adopted. In the common garden engines for watering, which are nothing else but small fire engines, the air chamber, as can be seen at a glance, is mostly globular, so as to be as compendious as possible, and thus conveniently portable. The water is pumped up into the chamber which is already full of air. Some of the latter is thus displaced, and has to take itself off through the exit pipe. What remains is eventually

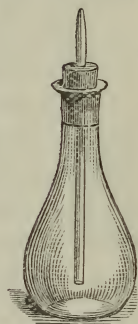
driven by the rising tide into the upper part of the chamber. There, as soon as the liquid has mounted so high as to cover the mouth of the exit pipe, thus barring any farther escape thereby, the inclosed air is, as it were, brought to bay. Being still, however, even in its last place of retreat, squeezed by the flood, which continues to be pumped in as before, it exerts in its turn a very powerful, but equable and sustained pressure of reaction on the water below it, forcing it in a copious stream through the exit pipe. To the outside end of this pipe is attached hose, called the "delivery pipe," made of india rubber, or leather, which can be turned so as to spout in any direction which may be required. A fire engine always consists of a pair of forcing



pumps, both feeding one and the same air chamber, since a fuller head of water, and a more vigorous and better sustained fountain is thus obtained, instead of the somewhat intermittent series of jets which would follow on the strokes of a single piston. Toy fire engines

which work extremely well are sold by tens of thousands at eighteenpence apiece and upwards.

Before bidding good-bye to the subjects which we have lately been dealing with as incidental to pumps, it may be mentioned that a working model of an air chamber can be made in a minute for nothing by anybody who may care to take the trouble. Fill a common glass phial bottle half full of water. Introduce a pipe (a bit of tobacco pipe will do) through the cork, and push it in far enough to make it descend into the liquid. On putting the bottle over a flame, the water soon begins to shoot in a brisk fountain from the top of the pipe. The reason of this, as is easily discerned, is that when steam is generated, as takes place when the apparatus is heated, the vapour presses, as it comes into being and expands, on the liquid below, squirting it in a lively waterspout through the pipe. The bottle and pipe, as is plain enough, form, constructionally speaking, an air chamber. This experiment may be made even still more easily, but with an effect which, not being of a continuing kind, is hardly so complete as that which has been described, by merely blowing hard down the pipe. The air in the chamber is thus condensed by pressure, and as soon as by the withdrawal of the lips, its elasticity gains free play, it causes a jet of water to leap up through the pipe.



A proper opportunity has now come for discussing a toy which goes by the name of the Cartesian diver, and which illustrates in a very neat and happy manner

several questions which we have discussed this evening. An hour ago, perhaps, you might not have found its acquaintance quite so easy to make as it will now prove. The toy displays three things principally; the elasticity of air, the absence of that quality in water, and the effect of reaction. The thing consists of a



tall glass bottle or jar, nearly, but not quite, full of water, and covered at the top with a small sheet of india rubber, which is kept in its place by a bandage of string. Floating in the water is a little glass figure of a man in a dancing attitude. On pressing the india rubber covering with the finger, the figure descends, reascending when the touch is light-

ened. If the finger is abruptly removed, the figure spins as it rises. Its behaviour will be found to be in direct and close obedience to the pressure used, since it can be made by the nature of the touch which is applied to sink to any precise depth which may be wished, and either remain at rest or spin there, and it will conform to the order communicated through the tip of the finger by twirling more or less vivaciously or not at all, during its ascent.

You would probably be well able, after a little reflection on the characteristics of its behaviour, to surmise the principles of its construction. But by lifting one of such figures out of his native element, a short cut may be taken by what is called autopsy, that is to say by ocular inspection of his body, to a knowledge of the influences which govern his actions. The figure, being made of glass, which is heavier than water, would sink, but that it is partly hollow, so that it contains a certain

quantity of air. The air, being lighter than water, buoys the figure up, just as a bladder supports a person who cannot swim, or as gas raises a balloon. The figure might with propriety be described as a water balloon. When uncontrolled by any foreign influence, it ascends to the surface of the water, and there stays, poising vertically, as it is caused to do by the weight of its feet which are made heavy with this object. But the bottle, according to one of the specified conditions of its arrangement, is not quite full. There is therefore a small inclosed precinct, forming a chamber of air, between the surface of the water and the india rubber covering above. When pressure is applied to this covering it yields, because both it and the air below it are elastic. The air in its turn presses like a spring on the surface of the water. But the water is altogether inelastic, so that it transmits the whole of the force which is applied to its surface throughout its own entire mass according to the orthodox practice of fluids. It thus conveys the pressure which is exerted by the finger to the air in the hollow of the glass figure, just as if it were a hard and stiff intermediary such as a piece of stick. The air in the hollow, being elastic, shrinks under compression, and the space whence it recedes is immediately, of course, occupied by the water which is urged forwards at its heels. The whole figure, now that a reduced proportion of its total bulk is made up of light materials, loses buoyancy to a corresponding extent, and sinks. With every degree in which the pressure is mitigated, the air confined in the body of the figure reassumes, in consequence of its elasticity, something more of its original volume, and dislodges more

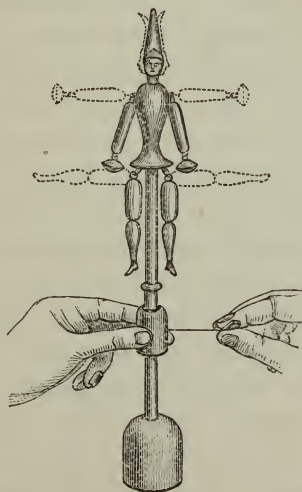
and more of the invading water. The figure thus, at last, regains its original specific gravity, that is to say becomes as buoyant as at first, and mounts once more to the surface.

Its spinning is simply caused by the action upon it which is induced by the issue of water expelled by the air, as this latter reasserts its territorial rights. The reaction in question is precisely similar in effect to that already described in the case of Barker's Mill, and of other mechanical contrivances which we have had under inspection. It need scarcely be added that the mouth of the hollow from which the water is discharged must so open as that the issue shall take place from, and the consequent reaction tell upon, one side of the figure only, for otherwise there will be no spinning. If the hollow, for example, were to open straight downwards from the crown of the figure's head, or horizontally from the centre of its waistcoat, the arrangement in the first case would impart a faculty for leaping, and in the second for darting backwards like a shrimp, but the whole capacity for executing pirouettes would be lost.



CHAPTER VI.

THE toy to which we will next pass is one of extreme simplicity but very instructive for all that, and it has a near relationship, mechanically speaking, to some of the greatest institutions of the universe. It also figures



in various engineering devices in almost the very same form as that in which it appears as a child's plaything.

It consists of a wooden doll fixed to the end of a spindle. The latter is caused to twirl by pulling a string which has been coiled round it, as is done with a top. A loose collar held in the hand supports it, allowing it at the same time to spin freely. It is what the toyshop people call self-winding, which means, as they use the phrase, that by a strong impulse adroitly given sufficient momentum may be imparted to the figure to cause it to go on spinning for some short time after the whole length of string which was bound round it has been uncoiled, so that it partially winds itself up again the reverse way, and thus assumes a condition of perfect readiness for a fresh start at a pull by the operator. The bandalore, which is a sort of travelling top, derives such charms as it possesses entirely from its self-winding faculty. The accumulated impetus which it gains in running down the string, aided by a sort of coaxing jerk from the hand of the manipulator, given just at the right juncture, and with a knack which is only to be acquired by experience, imparts to it a capacity for climbing again to the top of its tether. A hoop, or a wheel, allowed to run down an incline will, through the momentum which it acquires in the descent, partially mount an opposite declivity of equal height.

The figure on the spindle has limbs but loosely hooked to its body so that they may readily assume any postures into which the influence of the spinning may from time to time throw them. It will be found by experiment that the listless inertness with which they hang when the trunk to which they are attached is at rest, is exchanged for a more and more lively and determined tendency to rise at their extremities as

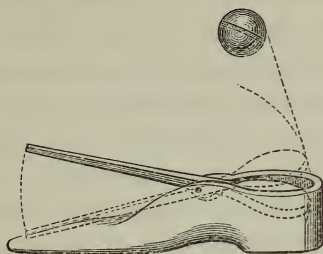
they swing round with increasing velocity, so that eventually, when travelling with considerable speed, they stand out horizontally like the arms of signposts. Why is this? Whatever steps we take in search of a reply to this question must, if they are to be effectual and worth their pains, start from a sufficiently early point on the proper route, which may be at the following well-established position.

When a body is found to be moving in any other course than that of a straight line, it is of an absolute certainty so doing under the influence of more than one force only. If the matter is considered for a moment, it will be seen that this must of necessity be the case. Nothing can be propelled otherwise than in a straight line, or, as it is usually expressed, otherwise than in a rectilinear direction. A boy cannot throw a stone, or shoot a pea out of a peashooter, so as to hit somebody round a corner. An artilleryman cannot reach the enemy on the other side of an intervening hill by firing cannon balls round the shoulder of it. He may, no doubt, pay his attentions in the quarter where he has ascertained his foe to be by directing them in a calculated track over the top of the hill, so as to drop his favours on the adversary's head on the other side, but in this case he knows that another force besides that which is born of the gunpowder, namely, that of gravity, will inevitably act on the shot with an effect, and in a manner, which can be previously computed, and he arranges accordingly. In other words, the curved path, or trajectory, as it is called, which a ball to be sent over a hill must pursue demands two forces for its production, and although the gunner can only

set a single one going, he knows that a second of ascertained power and direction will be of itself forthcoming, so that the requisite conditions for organising the whole proceedings are, in fact, at his disposal. The path, therefore, of a bullet or arrow, or any other missile, would always be in a straight line from its commencement to its finish if the only force intervening in the matter were the original one of projection. Similarly, when a bowl is trundled, it receives an impulse from the player's hand which is exclusively rectilinear, and cannot be otherwise. Its broad spiral sweep, eventually shrinking into closer and sharper convolutions, is due to the bending of its originally straight course by agencies which are easily to be detected and have been already glanced at. These begin to do business upon it at the very first instant that it becomes free from the absolute control of the player's grasp.

A body which is itself wheeling in a curve can nevertheless only communicate to another object the rectilinear element of the compound of forces to which its own particular movement is due. Witness the behaviour of a cricket ball, which traverses a straight path from wicket to wicket, though delivered by a circular swing from the arm of a roundhand bowler. Witness, too, the conduct of the ball jerked upwards from the trap in the game of trap, bat, and ball. The bowl of the spoon from which the ball is ejected follows, whenever it moves, a path which must of necessity be a fragment, or segment, as it is called, of a circle. The pin divides the spoon into two lengths, which are severally radii of circles, just as if each of them were the spoke of a wheel, the pivot the nave, and the path of the bowl the

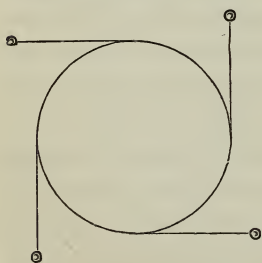
tire. The ball, however, is projected upwards in a straight line at what is called a tangent to the circle described by the bowl of the spoon. The meaning of



the expression tangent to a circle is not clear to everybody and may possibly, therefore, want explanation. It is necessary for our present purposes that it should be understood. A tangent to a circle is a straight line which, to whatever length it may be continued, touches, as its name implies, the circumference of that circle, but without cutting it. The tangent may be said to graze the edge of the circle at the particular point where the two meet.

Curvilinear motion, therefore, of any kind implies, under all circumstances, that more than one instrumentality is engaged with its production. Whatever forces may be at work, they are always resolvable into two, one of which strives to carry the moving body along a straight line, and the other to drag it inwards, that is to say towards some point or other on the hollow side of the curve which is described. The indirect contest of these forces is unremittingly sustained along the whole length of the path which is traversed. If, therefore, the balance of antagonisms is by any means

disturbed through some subtraction from, or addition to, the energy of either of them, the one which remains unimpaired, or which has gained some new accession of vigour, as the case may be, assumes at once a corresponding predominance. If the curve in which the moving body travels be such as to form part of a circle, the tendency of the pull inwards must, as will appear on consideration, be towards the centre. Circular movement is taken, for convenience, as the typical example of motion in a curve, and the pull inwards, which, in the particular case of the circle, is towards its centre, lends its descriptive name of centripetal, that is to say centrewards, to the drag on the scooped side of whatever bend is in fact traced. The term fairly enough represents the sort of force which it is intended to describe, and there is no sufficient reason for taking exception to it on the ground of its not being strictly accurate. The word centrifugal, which means flying from the centre, is indictable on the double charge of being both inaccurate and misleading, since it seems to imply the presence of some separate and independent force whose energies are specially and exclusively de-



voted to endeavouring to carry the moving body straight away from the central point round which its course sweeps. No such force is, or can be, in action. What is really at work is a force tending to propel the moving body straight forwards

at every point in its career, rather than in a curve. The itinerant object, therefore, when relieved from the

pull inwards, speeds right forward towards the quarter to which its face, so to speak, happens to be turned at the instant when it is surrendered to the control of the rectilinear impulse alone.

What occurs is illustrated by the act of slinging a stone. In the incidents to that proceeding, the stone, when it is swung round in order that it may acquire the impulse necessary for taking flight, describes a circle. The cord of the sling represents the centripetal, or detaining, force. The effort on the part of the stone, increasing in intensity with the growth of the momentum, and made at every instant during which the whirling in a ring is continued, to get straight away, is the centrifugal force, and the line along which the missile departs, when released, is a tangent to the circle in which it was speeding at the instant of its emancipation from control.

The Earth, in what may be called its aeronautic vogue round the Sun, furnishes an example of the operation of the two contending forces of which we have been speaking. Its orbit, as most people know, is the outcome of two agencies, one of which is the attraction which the sun exercises by its gravity, and the other an impetus, how acquired we can surmise, but do not certainly know, by which our globe has been sent coursing through space. Under the balance which prevails between these two forces, the Earth flits through the Heavens with unvarying regularity. Were the Sun, like a woman whose charms are waning, to lose anything of its attractiveness, our orb would forthwith scud right away into some unknown suburb of the Universe. It would not, however,

do this by the impulse of any force other than one of those of which we have just spoken, but under the conduct of the rectilinear impetus already described, unaltered in itself, and only producing a different result through being now allowed to run riot uncontrolled. Although the term centrifugal is thus seen to be fallacious, still, it must, by the rule of Hobson's choice, remain in our service, there being no other expression in current use wherewith to replace it; for "tangential," which is sometimes used, is an unfamiliar word, and not universally understood. The particular effect of the force in question with which we are concerned at the present moment is this, that a body revolving in a circle has always a tendency from the rectilinear element in its motion to recede from the centre of its orbit.

To apply what has been said to the toy before us. When it is at rest, as now, the arms of the figure hang idly downwards, since they are under the exclusive control of gravity, which brings their disengaged ends to the lowest position which they are capable of assuming. When the spindle is twisted, and the figure thus put into whirling motion, two forces are called into being. One of these is centrifugal, being, in fact, the rectilinear impulse communicated by the spinner: the other is centripetal, that is to say, directed towards the centre of motion, and acting as a power of attraction would do in restraining the moving object, or any of its parts, from breaking away altogether. This latter is found in the resistance of the links by which the several limbs of the figure are attached to its body, and thereby prevented from seceding dispersedly from the trunk. The tendency of the rectilinear force is, as

will be found if the matter is looked into, such as to incite every member of the figure which may be free to move to take up an attitude inclined at right angles to the spindle. Twirl the handle of an umbrella and the ribs will behave in a like manner. In the present case, gravity remaining, as it must do, a constant quantity, that is to say, unaltered in point of strength, it must necessarily be overpowered as soon as any force which opposes it, and which is capable of growth, acquires a preponderating energy. This takes place by degrees, when the toy is spun, for as the vigour of the centrifugal force is progressively raised, the limbs of the figure which are freely surrendered by the looseness of their jointing to the control of the power which becomes more and more completely dominant, rouse themselves at its instigation from their original apathetic posture of hanging idly downwards to that of standing out resolutely stiff and straight from the body to which they belong, like the arms of a sign-post.

From what has been said it is evident why a mop-head, when it is trundled, takes the shape of a circular flat disc, the reason, of course, being that the ends of its locks of wool all retreat as far as possible from the handle. The locks are prevented from shooting off altogether by being tethered at their inside extremities, but the water which is confined amongst them by certain detaining agencies, as long as they are at rest, is now, by the imperious mastery of the centrifugal force, started from its habitat, and scattered all round in a shower, which, like the mophead, of whose present figure it is in fact an extension, may be described as a flat disc, whose broad surface is at right angles to the

handle. A familiar illustration of the effect of centrifugal force when prevailing over gravity is afforded by swinging a vessel full of water round in a circle, like a stone in a sling. The water does not escape, for the same reason that the stone does not drop, whatever may be the attitudes, topsy turvy, perhaps, among others, which the mode of whirling may cause the vessel to assume at various points in its career.

Air may be dealt with in the same manner as water trundled from a mop. Parcels and letters used to be sent across London from the Railway Terminus at Euston Square to the General Post Office, a distance of a mile or so, upon tiny trains running through an underground tube along which they were in a great measure wafted by air thrown upon them from behind by centrifugal force. It would not have been convenient, or even possible, in so confined a space to employ a locomotive engine to draw the carriages, so the services of air were enlisted instead, in the manner to be now described. The tube was constructed of precisely uniform bore throughout, and with an inner surface which was perfectly smooth. The leading carriage was provided with appliances which, although gliding easily over the interior surface of the tube, fitted it with such nicety as to be tolerably airtight, so that the vehicle, when accoutred with these, became in effect, a plug, like the piston of a squirt. The end of the tube, at the further terminus, was closed by a valve, and the air occupying the interspace between this and the front of the train was partially exhausted by an air-pump. For reasons with which you are already familiar the external atmosphere would now exert a strong pro-

pellent force on the rear of the carriage, sufficient to bear it along. A blast of air thrown off from a wheel by centrifugal force was called in aid to give additional life and decision to the push.

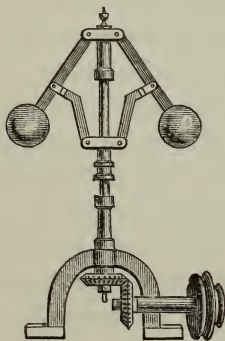
Such a wheel as has just been spoken of is formed of two solid and circular discs of metal placed parallel to one another so that the surface of one is near to, but does not quite touch, the surface of the other throughout its whole extent. The discs are a little farther withdrawn from one another at their centres than elsewhere, and round this point they are each perforated with holes. When the hollow wheel which is formed of the discs so adjusted as has been described is set in rapid motion, a strong centrifugal force is imparted to every portion of it and to the circular slab of air which fills the interior. It has already been mentioned that air clings with a good deal of obstinacy to the surfaces of objects with which it is in contact. The discs therefore, instead of slipping through, or past it, as they would do if the property which has just been referred to did not exist, by degrees impart much of their own motion to the contiguous atmosphere which intervenes between them. The air, like the water in the mop, being free to depart, when so minded, or when dragged forth from its retreat, is whirled off from between the open lips of the wheel, and blows in all directions which are continuations in a straight line of its course as it issues forth. The wheel is replenished by other air continually rushing in at the perforations which have been spoken of in the vicinity of the axle. The sustained blast thus generated helped to drive the Lilliputian trains which un-

unceasingly ran, like a weaver's shuttle, backwards and forwards, from Seymour Street to St. Martin's le Grand. Financially, I believe, the tubular railway which has just been described was not a success, and the undertaking was therefore wound up, but this was not owing to any vice in the mechanical arrangements employed.

After forming acquaintance with the contrivance by which, as you have seen, air is whirled round, and thus endued with a centrifugal force which converts it into a tiny hurricane, you will find it interesting to look up in any cyclopædia or book of mechanics, the word "centrifugal," and compare the account which will be found under that heading of a certain sort of pump with that of the pneumatic wheel we have been inspecting.

In introducing the spindle and figure toy to you I commended it to your attention as affording a clear and direct illustration of a principle on which mechanical appliances of the highest importance are constructed. We have since cleared the ground of any impediments which might have encumbered the course of proof of this statement, and it may now, therefore, be at once and fully verified. The spinning figure is usually one representing a lady. One hears of "giddy girls," but of all persons whose conduct would seem likely to lay them open to the imputation of giddiness, commend me to a little woman of this kind, spinning violently as she does. Giddy as she may be reasonably assumed to be, yet she attends to serious work, or, in other words, you must have seen this very toy, in almost the precise shape in which we find it in the nursery, made in

steel, playing a part of the highest importance in the management of steam engines. If you have not so noticed it, your habit of seeing things must indeed be a case of "eyes and no eyes." The arrangement which I speak of is prominent to view on almost every stationary steam-engine, and its appearance is so peculiar that one would think it could scarcely be overlooked, or fail to excite curiosity. The bronze statue which stands on the Holborn Viaduct doing duty, as the label on its base intimates, as an emblematical representation of "Science," holds in its hand one of the implements of which we have been speaking, which is thus taken, (as certain theatrical properties are held to be the garnish which is specially appropriate to particular characters, such as a wand to harlequin, and a hat with metal saints to Louis XI.) as being a fit and distinctive mark of the impersonification of "Science."



Its main features consist of an upright spindle, as in the toy under consideration, with two rods suspended therefrom, answering to the arms of the figure. At the ends of these rods are knobs, such as might very well

represent the fists of the little lady, if they were clenched, only that, as the rods are thin, and the knobs large and heavy, the idea of drumsticks is suggested, by which name, therefore, we will for the future call them. As the engine works, the apparatus, being connected with it by suitable gear, turns round and round, and always with a proportionate degree of speed. It is what is called the governor, and its use and action are as follows. The steam by which a steam engine is set in motion and kept going is generated, of course, in the boiler; and the activity of the brew which there takes place, is, and must be, irregular. When the fire is hot, it is produced with great rapidity. If the furnace be allowed to get low, the supply of steam is not nearly so quick and plentiful, and the result of this wide and incessant variation, if it were not met by appropriate provisions, would be that the action of the machinery would be very inconveniently fitful and capricious. Sometimes the engine would go a great deal too fast, perhaps dangerously so, and would take a meal of steam serpent-fashion, gobbling and gorging voraciously, and afterwards lapsing for some time into a languid and inert state. The demands, moreover, which are made upon the steam-power by the varying exigencies of the work which is to be done sometimes alter largely from moment to moment, and thereby another element of irregularity gains admittance. For the high pitch of energy which may be demanded at some given juncture for the purpose of overcoming, with the calmness of assured mastery, the resistance offered by the part of the task which is being, at the moment, discharged, would assume the character of excited vehemence, and

might perhaps run altogether to riot if it were to be still maintained in undiminished exercise after all opposition had dwindled away to little or nothing. The force, when no longer consumed or checked, would spend itself wholly in the production of inordinate speed. If it rested with the man in charge of the engine to adjust the supply of power to the fluctuating requisitions of each moment, this duty would occupy his close and unremitting attention, and it could not be satisfactorily discharged after all. So the engine is made to regulate for itself its own dietary of steam by the ingenious contrivance which has just been pointed out to you.

Its action is as follows. The spindle of the governor, an upright rod, is connected by toothed wheels with other parts of the engine, so that it revolves at the exact pace at which the machinery is for the time going. When the engine is conducting itself with proper sobriety, the spindle turns deliberately round and round as if it were an upright spit employed in roasting before a slack fire, and the drum-sticks hang idly down by their own weight. Whenever a better head of steam in the boiler imparts more animation to the proceedings, the rotation of the spindle becomes correspondingly enlivened, and thereupon, for reasons which have been so fully explained, the drum-sticks wake up and begin to open like the blades of a pair of scissors turned downwards; and as the speed with which they are whirled augments, they fly more and more decidedly apart. They are connected by rods with a loose collar, slipping with their rise and fall, up and down over the spindle, and controlling, through the intervention of appropriate tackle, the admission of steam from the boiler to the

cylinder, in which latter place it first becomes an operative power.

The balls which form the ends of the drum-sticks are purposely made of heavy lumps of metal, so that the centrifugal force, before it can raise them, has to overcome a strong opposition on the part of gravity which strives to hold them down. They do not, therefore, fly upwards on the least provocation so readily as the arms of the toy do. But this, of course, is so by design, and is as it should be, the reason being that serious work is imposed on the arms of the governor, since the duty rests with them, as has been explained, of moving certain mechanism, a business which in all cases involves the necessity of overcoming the resistance of friction, and sometimes that of gravity also, and they have, moreover, to fulfil this office with an unfailing certainty, smoothness, and regularity, such as would not attend the action of insufficient power. It is indispensable, therefore, that they should have momentum, which means energy of movement, and is the product of the weight of the moving body and of its speed, multiplied together.

To make this clear, it may be as well to give as illustrations three cases of a high degree of momentum, in the first of which both weight and speed are great, in the second the weight alone, and in the third only the speed, the other multiplier or multiplicand, whichever you like to call it, in each of these two latter instances being very small. A heavy shot thrown from a powerful gun will be an example of the first kind. Through its huge weight, and extreme rapidity of flight, it acquires the immense momentum which it is its whole business to possess, that is to say, it has an energy

of movement, which, on encountering resistance from the object which is struck, produces a crashing impact. An example of the second mode in which momentum may be composed will be seen in an ironclad drifting lethargically on a slack tide, with a movement which is perhaps not so much as perceptible to the eye. The vessel would be found, however, to be endued with sufficient energy of motion to crack like a nut any smaller craft which were to interpose between it and any fixed obstacle, such as a pier. Here, the vast ponderousness of the burly mass makes up by its composed, and apparently dormant, energy for the absence of speed. The third mode in which a powerful momentum may be constituted will be well exemplified by a sword-fish, a creature which has a body which is but slim, and of no great length, so that it is not at all heavy. The animal however can, with one peremptory thrust, dibble a hole, as may be seen by a practical example which is preserved in the Museum of the College of Surgeons in Lincoln's Inn Fields, through a vessel's copper sheathing and a skin of oak scarcely, if at all, less hard than the metal, in a manner which must be seen to be believed. The weight of the fish being so considerable, his charge must be like a flash of lightning for speed, as may be read in the extraordinary record which its effects, as exhibited, present.

Now the arms of the spinning figure in the toy might, no doubt, according to the formula which was given just now, be caused to possess as high a degree of momentum as those of the governor of a steam engine, if their speed of revolution were to be sufficiently raised to compensate for their want of weight. But

it would be difficult to endue them with any such headlong rapidity of motion as would be necessary to fulfil such a condition as this, and their behaviour, if their whirl were thus to become a whiz, would lack the staid sedateness which should belong to capable, yet gentle, mechanical agencies. The momentum which the drum-sticks with their heavy ends acquire with and by quick motion may be realised in conception when the curious but well-established fact is adverted to that massive iron wheels, when set to spin with extreme rapidity, have been known to fly asunder. In such a case as that, the centrifugal force and the weight of metal being both very large, and, consequently, the product of the two, when multiplied together, enormous, the momentum acquired by the outside rim, or periphery, as it is called, of the wheel becomes so powerful and violent (the energy of motion being, of course, greatest in that quarter), that it has been sometimes known, as has been stated, to tear that portion away, and hurl it to a distance. A similar occurrence has not infrequently happened with large grindstones. Some of you may probably have seen the process of stamping or cutting holes in metal by a die, or punch, as the case may be, brought down upon the surface which is to be operated on by means of a screw descending vertically through a fixed collar. The screw, in such cases, is worked by a cross bar, forming in effect two levers, and the latter is rendered capable of being endued with the momentum which is necessary for executing the work to be done with proper decision by being furnished at the end of either arm with a heavy metal ball. These balls are set swinging round by the operator, and the

blow which by their momentum they deliver through the screw at the point of impact upon the metal which is to be dealt with, is an effective one.

It may not be out of place to mention here that another self-acting regulator of machinery is sometimes used in cases where the governor would be unsuitable, as, for example, when the motive power, or "prime mover," as it is called, is a weight or spring, so that, consequently, there is no steam to cut off. The contrivance in question consists simply of two or more vanes, or fans, set upon an upright spindle with their surfaces vertical so as to be flat to the air when in motion. The spindle, as in the case of the governor, shares, through some appropriate arrangement, the motion of the machinery to which it is attached, so that as it revolves the fans encounter from the air a resistance whose energy increases in a multiplied proportion to the speed of motion. This statement will be accepted as true when it is remembered that if the fact were otherwise raindrops (not to speak of hailstones), as the accelerating power of gravity is exerted on them, and with constantly augmented effect throughout their whole course of descent, would eventually acquire so extreme a degree of momentum as to dash themselves on the earth with the force of shot from a gun. Whenever, therefore, the revolution of the fans becomes unduly accelerated, the opposition of the air is roused to correspondingly vigorous action, and the latter progresses in strength by steps which may be said to outpace any advances of its exciting cause, thus responding effectually to the need of check by which it has been called forth. A fan regulator is of more complete efficiency than a governor

in one respect, inasmuch as it combats in its own person forces running to riot, but it does not, like the governor, cut off, contract, or economise, superfluous impulse.

A simple proof of the fact referred to just now that the resistance which a fluid such as air or water opposes to motion multiplies with increase of speed, and (for this is only, of course, another way of stating the same proposition) falls by a proportionately rapid scale with its diminution, may be noticed at any dock or port. Large ships may be seen towed from one station to another by a rope from a small boat, which latter is rowed, perhaps, by no more than a couple of men. The water offers so mild a resistance to the very slow glide, which is all that is wanted or desirable in a confined space, that the insignificant force which is employed suffices to draw a huge mass.

There is another contrivance which should be mentioned as acting on the same principle as the spinning doll, which is employed for insuring the safety of men who work in mines when descending or ascending deep shafts to and from their scene of labour. The rope by which the basket used for their conveyance is lifted or let down is coiled round a revolving drum like thread on a reel. To the axle of this drum, or to some part of the machinery immediately connected with it, arms are attached, which are furnished at their outer extremities with grappling hooks. The connection of the arms with the axle is by a loose joint, which enables them to swing quite freely. As long as the drum revolves only at the staid pace which is safe and proper, the arms hang passively downwards, but if any slip of the gear-

ing of the machinery should occur, and the rope begin to run out with undue speed, the arms, extending themselves through swinging upwards by centrifugal force, catch with their grappling hooks fixed iron rings, and the machinery is thus instantly brought to a standstill. The rings of course are so situated as to be just beyond the circle described by the hooks when the arms are not extended. They are placed however in such immediate vicinity to the orbit of the hooks as to catch them at the very first instant when this becomes enlarged, that is to say at the earliest moment when some slight extension of the arms is both the result and the proof of the machinery having broken from control. It is of course of extreme importance at such a crisis as this that the running out of the rope shall be at once arrested, since the weight which is no longer properly sustained gathers increased momentum, more violent and dangerous in itself, and more difficult to curb, with every additional inch through which it is permitted to fall. The safety catch which has been mentioned was formerly used, and occasionally is so still, but more handy and compendious devices are now available for the same purpose.

The spinning toy which we have been discussing is, as you now see, almost more than a type or shadow of a very important mechanical contrivance in constant use, namely, the governor, being in truth, as far as it goes, almost the identical thing itself. It only falls short of it in respect of certain additions which do not alter the nature of the source of action, though they render the plaything a grave and important functionary. The principle of the governor is also concerned,

as was observed in introducing the subject, with some of the greatest features of Creation. This proposition will be established if the behaviour of the doll, when spun, be shown to be due to, and to illustrate, the very same agency as that by which many, if not all, of the worlds which people the universe were formed, shaped, and were, and still are, ordered in their goings. A perception of this truth must be gained by reverting once more to the precise effect which spinning produces upon the toy. The centrifugal force which is generated by the movement in question possesses, as has been seen, a tendency to carry the arms and legs of the doll as far away as possible from the spindle on which they are spun, or, from what is called the axis of rotation. This is visibly observed to be true of as many portions of the lady's body as are capable, through swinging freely from a point of loose attachment, of altering their position, and if the experiment were to be made, the same thing would be found to hold true, as indeed we know must be the case, of the whole figure. If, therefore, her person were made of butter, or clay, or of any other substance tenacious enough to hold together as one mass in spite of the efforts of a force of moderate intensity to tear it asunder, and if it were yet at the same time of a texture sufficiently yielding to allow the exterior contour of its form to be moulded to any shape which the result of the struggle between the disrupting agency in question and its own cohesiveness would naturally lead it to assume, and if the toy so constituted were to be set spinning, the following course of events would be witnessed. For reasons which a little consideration will disclose, the figure

would in the first place betray an inclination to corpulence about the waist, and this disposition would pronounce itself with constantly increasing emphasis. The same tendency continuing to predominate, substance would be drawn towards the middle from the limbs, so that they would be first depleted, and eventually absorbed altogether, being taken up for filling the ever-expanding girth about the hips. The figure would thus at last become all waist, that is to say, a ball. If the spinning were to be still continued, and with increased velocity, the figure would become by succeeding transformations, first, in point of shape, an orange, then something flatter like two saucers joined at their edges, and, after that, a mere thin disc, till eventually even its power of consistence as a whole would be overcome, and its various component atoms would part company, each flying off on its own separate and independent course, like the drops from the head of a trundled mop.

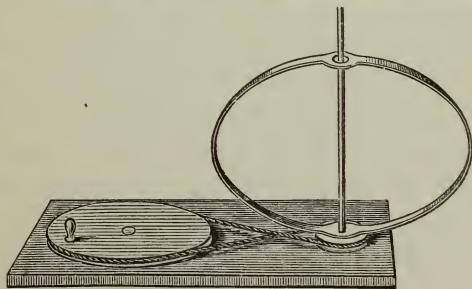
There is very good reason for believing that the Earth owes its existence as a mass possessing a distinct individuality of its own to having been shot off in the condition of a small whiff of haze from some larger cloud of matter at the juncture when the complete coherence of the main body of vapour was overcome by centrifugal force. Whether this be so or not, it is certain that it acquired its existing shape, which, as you probably know, is orange-like, or what would be technically called "an oblate spheroid," through the operation of the very same force which causes this toy when spinning to extend its arms. The Earth, which we believe to have been at first gaseous in composition, and afterwards liquid, now consists, as we know, of an

assemblage of varied, but substantial materials packed inside the thin crust on which we live. If the North and South Poles were the two ends respectively of a real pole on which the globe revolved as on a spit, the inevitable tendency of a more or less viscid lump, such as Mother Earth was in her juvenile days, would be, under such conditions as have been imagined, to bulge out at the waist, that is to say at the Equator, and to retreat into itself at the poles. The Earth does, as a matter of fact, spin round an axis of motion whose position coincides with that of a straight line drawn from pole to pole.

If any Arctic Expedition to be hereafter undertaken for investigating what may be called the crown of the world's head ever reaches that goal and end of its journey, it will not, according to popular anticipation, find the North Pole sticking up out of the snow in order to form a flagstaff for the Union Jack, nor, it may be added, will the climate be found genial, although a position at the back of the North Wind having been gained, a haven will have been reached which Boreas by his very nature is precluded from touching otherwise than with the extreme edge of his coat-tails before making a start to chill and torment the world down South. But a curious phenomenon will be observable, which will be quite intelligible to any one who understands this toy, for one explanation elucidates both. The prodigy in question will be the progressive increase in weight of everybody and everything as higher and higher latitudes are attained. *E. g.* a packet of tea weighing a cwt. in London will gain towards half a pound. Pendulum clocks, also, will be

found to go quicker. The reasons why these things will be so are not far to seek for any one who may care to stir in quest of them. But to diverge into them at this moment would render our track too much of a zig-zag, and we have already, perhaps, run off the rails of our main line into too many of such sidings. In accordance however with the principle which is contended for as being certainly and in every sense true, that nothing is to be thoroughly understood until viewed in all its bearings, so that these ought to be, as far as possible, even if it be but cursorily, indicated, it is proper to suggest, without minutely explaining, two interesting experiments which may be made by anyone in private, and which illustrate the question which we were discussing just now as to how the Earth should be taken to have come by its actual figure.

The first of these is a common way of showing only how our globe at some period or other of its history, perhaps at its birth, or perhaps (for this has been shown to be possible) not till a later date in its existence, acquired the peculiar and well-known contour of its mass.



The apparatus required consists of a hoop, made of some heavy, but elastic, material, and placed in a vertical

position. It is fixed in that attitude by being fastened at its lowest point to an upright rod. The rod passes freely through an open hole, or collar, at the top of the band which forms the periphery of the hoop, and it is equipped with suitable tackle, of which a winch and some multiplying wheels are the main features, by which a rapid motion round its own axis, that is to say round the central line of its length, can be imparted to it. When it is made to rotate, and with it, necessarily, the hoop, since they are joined together, as has been said, at one point, the latter will be found, as would be expected from the considerations which have lately become familiar to us, to lose its circular form and assume an oval one to a degree precisely corresponding with the rate at which it spins, that is to say, with the amount of centrifugal force which its constituent particles acquire. Its top being enabled to descend freely down the rod, which it merely encompasses, without clasping, the hoop squats, as it were, more and more, the faster it spins. The demonstration which this experiment affords is sufficient for its one purpose, and its bearing on the history of our globe's structure is obvious. It may here be mentioned that the deviation of the Earth's figure from true sphericity, that is to say the extent to which our orb departs from the character of a completely round ball, is as follows. At the Equator its diameter is about 7935 miles, and it is about 35 miles less at the Poles.

The second and more delicate experiment which was recommended to you, while supporting, and with no less decision, the same conclusion as that which is established by the behaviour of the revolving hoop, is

far more suggestive and full of instruction. It involves however, so much delicacy of manipulation that it could not easily be shown to a large body of spectators, so that it must be made the subject of private enterprise. It is to be executed as follows. A globule of oil is caused to float in the centre of a mass of transparent liquid. The adjustment of the conditions under which the necessary equilibrium of the fluids concerned will be procured may be brought about by diluting spirits of wine, which are lighter than oil, with water, which is heavier. The right proportions will be readily ascertainable by experiment. The mixture must be caused to have the same specific gravity as that of the oil which is used. In other words, such a compound of lighter and heavier ingredients is to be made as that any given quantity of the liquor thus brewed would, if it were put into one of the saucers of a pair of scales, exactly balance in weight an equal bulk of the oil placed in the other saucer. The globule of oil, when the adjustment which has been described has been accomplished, will float in the prepared fluid without any disposition either to rise or sink in it, so that by a little gentle management it may be persuaded to take up and retain any desired position within the body of the liquid by which it is enveloped.

If a straight piece of wire be now made to descend through the middle of the globule, so as to form, in effect, a spindle, and be then steadily and delicately twisted round by the fingers or by some other suitable agency, its motion will by degrees communicate itself to the sphere of oil, which may thus be brought to rotate on its own axis. As its speed of revolution

augments, the globule will pass through the successive phases of a spheroidal figure of a flatter and flatter character into a thin disc. Ultimately, if the progressive rate of the whirling motion be continued, a phenomenon, which the experiment with the hoop stops short of, will be presented by a flat ring being thrown off, so as to form a sort of halo, which, although it preserves no contact with the edge of the disc from which it will have disengaged itself, and therefore keeping up no communication with the wire axis, its hitherto source of motion, will still continue to spin round the nucleus of oil, and at the same pace with it.

Here is manifested in a striking form the effect of centrifugal force when acting on a plastic mass of matter such as the Earth certainly was when it first took a definite and permanent form. The action of the force in moulding a ductile substance into various shapes, which are severally the results, as also the registers, of its successive stages of energy, is in the first place witnessed, and its disruptive power, when its intensity reaches a certain height, is subsequently displayed. We have in evidence before us, in the experiment which has been described, the principle of the Governor, as seen when at work in a wider sphere than in a steam engine, or in the toy, arranging the constitution of the universe, and conducting some of the biggest processes of Nature. We see at the same time why, as was stated just now, it occasionally happens that a grindstone will fling itself to pieces when its rapidity of spin becomes extreme, and we cease to wonder how it can be that a flywheel, albeit constructed of strong and sound iron, is liable under

similar conditions to a like disaster. And last, but not least, we are confident that we are reading, as surely as though it were written in clear characters in an authentic record, the true history of the birth and continued existence of Saturn's Ring.

A working diagram of the different phases which a plastic mass assumes when set to rotate may be seen any day at a pottery, where rough lumps of soft clay are by this means quickly, neatly, and effectively converted into thin crusts, as dough is by a rolling pin, from which condition they readily pass at the touch of the workman into vessels of any desired forms. The "potter's wheel" is a familiar name even to those who have never seen the process just described, or troubled themselves to imagine what its character may be. Glass, which, when fused, is of a glutinous consistency, is spread like potter's clay into thin sheets, suitable for windows and other multifarious uses, simply by being taken up in lumps from the melting furnace at the end of a bar, and then whirled round.

It may be mentioned that the particular arrangement and sequence in which the concentric layers of matter which constitute the substance of the Earth as a whole are stowed within its figure was dictated by the same forces as those which shaped its globular form. The combined effect of the agencies which have been mentioned would be, speaking very roughly, to build up the fabric of the Earth by successive deposits superimposed one on another like the coats of an onion, the loosest and lightest outside, and the density and weight of the other members of the series increasing up to the centre. There are, as need scarcely be said, no such separate and

distinct beds of material, but the whole mass, as we have full reason to believe, gradually thickens from the exterior surface inwards. The idea of layers was merely suggested for the purpose of imparting the notion, which is a true one, that if the closeness of texture of the Earth's body were to be appraised by reducing the globe by means of stripping from its surface successive envelopes of matter all of one given depth, these spheroidal crusts, or shells, whether taken individually or as a series, would be found to become more and more dense in a course of regular progression from the outside towards the centre. This state of things which was theoretically to be expected has been verified, through experiments made by means of the pendulum, as that which actually prevails, and it has been found that the innermost strata have a density which is at least four times as great as that of the outer coat on which we live.



CHAPTER VII.

WE will now turn to our dear old friend the common peashooter. If the sources of its attraction for boys were to be analysed, they would probably be found to reside, like those of partridge shooting, partly in being connected with the predatory instincts which are indigenous in human nature, and partly in the satisfaction which attends the prosperous accomplishment of any feat requiring precision and adroitness of execution. But in the view of boys with healthily constituted dispositions an additional joy belongs to pea shooting in that it can be made a not inconsiderable means of mischief and annoyance, the pea being capable of being driven with so much force as to damage an eye or break a pane of glass. A peashooter in its magnified form, when it becomes what is called a blow-tube, may be used for killing small birds, or for shooting darts at a target. There is but little, but still just something, which is worth a moment's notice in the action of a peashooter.

Take a pea, and try to shoot it by your breath, but without a tube. It will travel no distance at all,

not even if you blow as King Lear adjured the winds to do "till you crack your cheeks," or like the frog in the fable, as given by Horace, "*si te ruperis.*" Why is the force employed under such circumstances so void of effect? A glance at a river or brook running into the sea, or into any large tract of water, will supply the answer to this question. A river which, as long as it is confined within a narrow channel, possesses a certain degree of energy of flow, loses all its power of progress, though without encountering any rigid obstacle, directly it enters a lake or the sea. For it then dissipates its forces, spending them on an inert mass of water, which calmly and silently absorbs the stream and its impulse, its body and life, together. A precisely similar fate befalls the gush of air which issues from the lips when a puff is given. In the absence of any suitable contrivance for preserving to the outrush of breath its character of a stream, the current wastes its power in communicating to the atmosphere in its immediate vicinity an impulse which is weak through the infinite subdivision of its energy exerted as this is in all sorts of directions. When, however, a blast is delivered into a peashooter, the current of air is set going along one particular line only, and it is kept strictly to business, so that it rushes through the tube like a torrent through a gorge. Its impetus, unlike the sustained force of a stream, is a hasty spasm of force which is soon exhausted, and even if it survives so long as to reach the muzzle of the peashooter, it is then, of course, at once and finally squandered abroad. But by that time it has communicated a lively force of projection to the pea. The increase of mechanical potency

which impetus acquires by transference from a fluid such as the air to a rigid body such as the pea should be noted, and the reasons why this is so should be considered. The clear perception of these matters which is easily to be gained by a trifling exercise of thought is necessary to the understanding of the main point in the action of a peashooter, to wit, the effective dispatch of the pea.

The barrel of a gun is obviously, as far as the principle of its design is concerned, the same thing as a peashooter. A bullet, placed upon an unconfined heap of gunpowder, which is afterwards fired, will be carried but a very little way, for although an abundance of power is generated, this is directed into no set channel; it is "*vis consilii expers*," and is thus void of any business-like effect. Only some fractional part of it is exerted upon the bullet. On contracting the field of the powder's action by a tube, that is to say, by a gun barrel, a very different result is obtained.



CHAPTER VIII.

WE will now turn to balls, which may claim to be not only toys, but something more. Marbles, billiards, tennis, cricket, football, and a hundred other pastimes are, as everybody knows, nothing but ball-play in one form or another. No games have been so universally popular, or through so many past ages, as those with balls. The word "ages" is advisedly used. Balls were favourite instruments of amusement in the time of Plato, that is to say about 2300 years ago, and the description which he gives in "Phædo" of the kinds which seem to have been the most popular in his day applies with curious exactitude to some of the varieties which are still common, and of which you may always see basketfuls on sale in the Lowther Arcade, and at every toyshop. The name "Pall Mall," marking, as it does, the place where a certain game of ball known by this title used to be played, is a standing testimony to the favour with which amusements of this kind were formerly regarded. There is nothing new under the sun, and Croquet, which came into vogue a few years ago, to be the fashionable craze for a while, and be

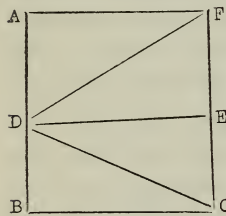
then discarded for pastimes of later invention, had some points, as it would seem, of resemblance to "Pallmall," since the tackle used in both cases appears to have been of the same order. The balls and long-handled mallets which constitute the stock in trade for Croquet have their "analogues," or items with which they correspond, in the implements used in Pallmall, as is shown by the etymology of the latter name. For "pall" is merely the Latin "pila," which reappears in modern Italian as "palla," a ball, and mall is the Latin "malleus," Italian "maglia," French "maille," and English "mallet," the hammer by which the ball is struck. It would take a long time to give any succinct account of the various games with balls which have been in vogue at one period or another. We can only give attention at this moment to some of the mechanical principles by which the conduct of balls is regulated.

Suppose an elastic ball to be thrown against a wall. It comes straight back. So, also, does it come straight back if it is dropped perpendicularly on the floor. But if it strikes the wall or floor in some other manner than that which we have called straight, that is to say otherwise than at a right angle, it retreats from the point of impact in a course which is precisely as oblique as that of its previous approach. Why this is so should be ascertained.

Suppose, then, A
|
B to be a wall, and that a ball is thrown against it from any direction. If the ball is utterly inelastic, its motion will be arrested by the surface of the bricks, and it will tumble dead to the ground at the foot of the wall, just as a pat of butter or a lump of clay would do if thrown

in the same manner. There is a graphic picture in Tennyson of seabirds which flying against a lighthouse in a storm "Dash themselves dead"—suddenness of impact and consequent and immediate destruction of life and motion are here vividly presented to the ear as well as to the eye. If the ball be more or less elastic, and strike the wall flat on its face, it will return after the collision towards the point whence it started. If it be highly elastic, it will come back with a force almost equal to that of its projection, or, in more popular language, nearly as hard as it went. If its elasticity be but feeble, then the impetus with which it is dispatched on its return journey will be correspondingly languid, so much so, perhaps, as to die out altogether at a more or less early stage on the homeward route.

Now suppose the ball to be perfectly elastic, and to be thrown so as to hit the wall obliquely as it would do if it travelled along a line such, for example, as CD .



Whither will it betake itself on its rebound? The parallelogram of forces will supply the answer to this, as to so many previous questions to which we have sought replies. Draw DE from D at right angles to AB , and complete the parallelogram $BCED$. Then CD will be the diagonal, and a force represented in power and direction by CD will at the point D be equivalent to the resultant of the two forces BD and ED . The ball therefore when at its point of impact D may be taken to be inspired by the two forces BD and ED . The blow against the wall is a *coup de grâce* to the force ED , killing it outright, since it can carry the ball no

further. But, as was shown not long ago, reaction is in all cases contrary in direction and equal in vigour to action. The force ED , therefore, by the outlay of its own vitality generates a force DE which acts in a particular manner to be more fully described presently. BD remains wholly unaffected by the impact at D , since the wall can, obviously, exercise no resistance to motion which is parallel to its surface. The position of affairs, therefore, is changed by the collision at D from the case of a ball moved by CD , that is to say by BD and ED jointly, into that of the same projectile impelled simultaneously by BD and DE . Continue BD in the same straight line to A , making DA equal in length to DB , and complete the parallelogram $DAFE$. The resultant of DA and DE will be the diagonal DF , and the ball will be landed by DF at F . DF makes an angle with DE which is equal to that made with it by CD , or, in other words, the degree of obliquity of the rebound depends on and precisely corresponds with that of the incidence.

The ricochet of a cannon ball, described by a technical term which has been appropriated by the language of artillery to designate the bound of a projectile of a particular kind when it has been purposely dispatched in such a manner as to skim the ground after the fashion of the missile in the game of ducks and drakes, takes place of course in strict conformity with the mechanical law which has been stated. The same rule governs the rebound, or, as it is called in this particular case, the "reflection" of light from a smooth and bright surface. The rule which defines the conditions under which rebound takes place being most noticeable, and having for many reasons attracted the most attention in the case of

light, has been formulated in terms which refer to that particular instance of its operation, although, as has been seen, it is more widely applicable; it is thus known as the law that the angles of incidence and reflection are equal to one another. It is proper enough that the case of light should be selected as the typical one to which the terms of the law should point, for in that instance the statement as to the equality of the angles of incidence and reflection holds good in a precise sense. In the case of rebound the result is only more or less approximately in conformity with the formula, since, as has been said, there is no body which is perfectly elastic.

To return to the circumstances under which the rebound of a ball takes place, and which require some further examination. The ball whose behaviour was under consideration just now was supposed, for the purpose of making the conditions of the problem as simple as possible, to be perfectly elastic. From what was said a short time back it will be understood that elasticity, as tending to produce rebound, is the quality of structure or constitution in virtue of which the moving body, while freely allowing some momentary alteration of its form to take place under pressure, that is to say under the force exerted upon it by reaction at the point of collision with some fixed obstacle, immediately re-assumes its former shape, as, and when, permitted to do so by the diminution or cessation of that pressure, that is to say as soon as the original momentum, being spent, ceases to excite what is tantamount to action on the part of the resisting surface.

Now no material, as was stated just now, is perfectly elastic. The india rubber of which the most

elastic balls are made opposes some antagonism to the temporary disarrangement of its component particles under the blow which reaction, as has been explained, virtually inflicts, and it does not readjust the contour of its original figure with a degree of energy quite equal to that of the force by which its original shape was altered. A certain part, therefore, both of the force of action, and of that of reaction, will have spent itself through some channel other than that which conduces to the production of a rebound; this ineffective portion will, as some of you no doubt know, have taken the form of heat. This is a point on which we can only bestow a passing allusion, since the time at our disposal, like the india rubber of which we have been speaking, is not infinitely elastic, and cannot, therefore, be so stretched as to include everything within its compass. It was necessary, however, to guard against the imputation or suggestion of inaccuracy by mentioning that the conclusions to which the working of our problem led us as to the eventual position of the ball when the force of rebound has been finally spent, will not be sustained by actual experience as being found to be in practice entirely true. For predicating what this position would be in the case of any given ball thrown against a fixed object at some particular angle, and with a stated amount of force, it is necessary that the precise degree of its elasticity should, as one of the first essential conditions on which the result must depend, be ascertained, and taken into account, and that certain other data should be furnished and their effect computed.

What has been said as to the series of occurrences

which results in producing the bound of a ball is the source of a familiar phenomenon of quite another kind to which it will be worth our while to refer, since it will illustrate the course of events which has been described, and help to clench your recollection's hold upon them. Suppose, then, that a bullet is tossed gently through a window pane. The destruction which it causes in its passage is great, and widely spread. All round the hole which it makes, and for some distance in every direction, the glass is cracked and starred. The degree of mischief which is altogether done is found to be pretty nearly in inverse proportion to the rapidity with which the bullet moved, that is to say, the smaller the speed the greater the destruction. This result is so noticeable and clear that it can never have failed to attract attention, and in the old days of naval warfare it was procured by express design, in the manner which shall be explained.

In those times the general character of a battle at sea was mainly that of the engagement, in pairs, of a multiplicity of ships, each battering exclusively its one private and particular antagonist, like the warriors before Troy, who, according to Homer, seem to have conducted their hostilities almost entirely by means of duels. The leading principle of naval tactics was that each ship was to lay itself alongside of the first enemy who presented himself, for the purpose of a mutual pounding at close quarters. The couple, frequently lashed together for the more systematic conduct of the business in hand, poured broadsides, as fast as they could be fired, into one another's ribs, till one of the two hulls was pretty well smashed up into lucifer

matches. In fighting under such conditions as these, it was advantageous, and usual, to employ much smaller charges of powder than were required at long ranges, for the lower the velocity of the ball, provided only that it had just sufficient energy to penetrate a ship's skin, the more destructive was its effect in the way of producing wide-spread rents and splinters. The reason of this was as follows.

When collision takes place between two bodies one of which is stationary and the other in rapid motion, such particles of the former as happen to be situated at the point of impact receive, of course, a blow whose tendency is to push them backwards from the situation which they occupy, and, through them, to drive the mass which is behind them into retreat. If the blow is sufficient to overcome the natural inertia of the body which is at rest, and if this latter be at the same time free to stir, movement is gradually imparted to it. But it takes a certain time, however short, to induce change of place in the whole mass which is thus impelled. This statement must be taken upon trust as true, if the reason for it does not happen to be at once obvious to you, since to explain the point fully would require a longer episode than can be afforded to it at this moment. Now if this modicum of time, which, however infinitesimal it may be, is none the less of essential necessity for the purpose which has been mentioned, be not allowed, the particles which first encounter the blow have, as it were, to bear its whole brunt and effect in their own persons. Thus, suppose that a bullet be discharged from a pistol against a pane of glass. The blow is in the highest degree smart and

sudden. The small circular field of glass which is equal in extent to the sectional area of the bullet, and which is therefore subject to its direct attack, is driven before it too peremptorily and hurriedly to allow it time to impart any of its movement to the particles which are in its immediate vicinity. It is thus carried before the bullet, leaving a hole behind it which is almost as clear and clean-cut as though it had been punched. If, on the other hand, the stroke from the bullet be but a languid one, time is allowed for the accomplishment of a drag and jar on the surrounding tract of glass, which is thus torn and shattered.

The time-honoured feat of firing a tallow candle through the panel of a deal door ceases to be marvellous when the reason why an uglier wound, as was expounded just now, is inflicted by a comparatively hesitating shot than by one of greater decision of character, has been apprehended. The two phenomena are, obviously enough, all of a piece with one another. The fact to which the celebrated Engineer, Sir I. Brunel, called attention, that the mode of breakage of a bar of iron displays the nature of the force and the degree of time used in the operation, is explicable by the same reasoning as has been applied to the fracture of glass. If a bar of iron be gradually reft in sunder, or, so to express it, slowly worked apart by a series of dull thumps, the structure which is laid bare at the place of rupture is fibrous, which means more or less drawn out into threads. If, on the other hand, it is struck into two pieces by a single brisk and decisive bang, the exposed surfaces of the wound disclose a crystalline character, that is to say, a fracture of a sharp and

gritty kind, indicating that the continuous arrangement of the particles constituting the bar was destroyed at the point where the blow fell so instantaneously that the whole effect of the stroke made itself felt, and ended, before any lateral disturbance could extend into the adjacent parts. The relation which phenomena such as have been described as consequent on impact bear to those which occasion and attend rebound needs no comment.

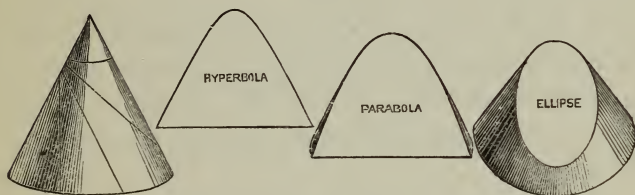
The spectacle of a bounding ball following with exact and implicit obedience, at each and every point of its career, the joint dictates of the forces to which its motions are due tends to induce a more real and vivid appreciation of the fact that the nonentity which goes by the name of Chance has no share whatever in the proceedings. It also invigorates the perception of the truth that anything which is cast at random into the air, although it may present some delusive appearance of enjoying more absolute liberty than is possessed by objects which are under the immediate dominion of powers by which they are visibly controlled, is never surrendered for a single instant, or to the extent of a hair's breadth, to the caprices of accident.

A stone, for example, when flung by a school-boy, does not manifestly pursue a course which is prescribed to it by clear and fixed conditions, yet throughout the whole of its journey, including its eventual fall to the ground, it is as despotically governed and directed by a set of known forces as it was by the hand of the thrower before it quitted his grasp. Given the conditions under which it is projected, its trajectory, that is to say its entire line of flight from its start to its finish, can be

accurately foretold. The character of the track which is pursued, unless the stone has been thrown quite straight upwards, is of a very interesting kind, as will appear presently. There will be three forces acting upon it, during the whole time that it continues to possess any motion. One of these will be, at the first start, the impulse then imparted to it, and afterwards, the continually dwindling residue, for the time being, of that impetus. The second will be the force of gravity pulling it towards the earth; and the third will be the resistance of the air opposing its progress whatever may be the direction of motion. Sooner or later either gravity, or the resistance of the air, would inevitably, of itself alone, prevail against and destroy impetus, however strong, because this last is a finite force whose whole energy is put forth at the first onset, and is never afterwards recruited. The attraction of gravity, on the other hand, is an inexhaustible power, and the resistance of the air is actually generated by the passage of the missile as it elbows its way, so to speak, through the throng of particles which make up the atmosphere. This resistance never ceases to oppose impetus, and thus gradually tires it down by an antagonism which is pertinaciously maintained so long as there is even the smallest and feeblest remnant of motion left for it to exterminate.

If the stone be thrown straight upwards in a perpendicular line, it must plainly enough return by the same way that it went as soon as the momentum with which it was originally gifted has been subdued by the adversaries which have been mentioned. If it be flung in any other direction whatever than a verti-

cal one, its path will be in some variety or other of the particular species of curve which is termed a parabola. We cannot go into the mathematics or even any precise description of a parabola here, but if you wish to see a figure of the kind in question, a model may convey a sort of notion of what the curve in question is in its general personal appearance, although giving no idea of its peculiar characteristics.



A parabola is a section of a cone ; that is to say, if a cone such as will be described in a moment were to be sliced through by a cut made within certain limits, the exterior boundary of the surface which, as is to be conceived, would be laid bare by the passage of the knife would be, in form, a parabola. A cone is a figure somewhat resembling a pyramid in its general aspect. Its top or apex is a sharp point. Properly speaking, it has no bottom, or base, at all. For it is supposed to be generated by two straight lines of indefinite length which meet, like the legs of a pair of compasses, and are then twisted round an axis common to both as if they were the arms of the governor in a steam-engine.

No complete presentment, of course, of the indefinitely large figure which would be thus traced can

be given by any model or diagram, or even indeed, except very imperfectly, by the imagination, which can only cope with such magnitudes, of whatever kind they may be, as are comprised within small and strict limits, but the model of a certain finite portion, adjacent to the apex, of a cone will serve for our present purposes. It will be observed that a sugar-loaf does not come under the definition of a cone which has just been given, since it has a shoulder, or bulging portion all round, near its tip; while in a mathematical cone a line drawn from any point on the exterior surface of the figure to the apex is straight. Pastilles, military tents, extinguishers, and the cut ends of pencils are true cones.

Now suppose a section of the wooden cone which is before you to be made by slicing it aslant in any direction, provided only that the cut is made in such a manner as to enter a side of the figure, and go through its base. A model like this, which is readily to be obtained at almost any optician's for a shilling or so, is for convenience already divided into such sections as are required, so that it has only to be taken apart to display them. The outside edge of the wound which results from any cut thus executed is a curve of two parts or limbs, and somewhat resembles as a whole one of the terminal portions of an oval. Such a curve is called a parabola. Many comets move in parabolas. If the cone were to be sliced in another and more horizontal direction so as not to traverse the base, the edge of the cut would be what is called an ellipse, which represents the path of the Earth and of other

planets. Carved after a third fashion, more perpendicularly, the divided parts of the cone would present what is call an hyperbola, a curve which some comets, perhaps, describe in their movements.

It thus appears that unless some idea of the nature and properties of the curves which are presented by the sections of a cone be acquired, the motions of a ball cannot be understood. The study of the law which governs the conduct of every ball and every stone which is thrown into the air is hence seen to be a necessary preliminary to the acquisition of the first rudiments of elementary astronomy.

Exception might of course be taken to the foregoing rough account of a cone on the ground that the figure in question is not quite so simple as the description which has been given of it would suggest. It might be objected that the idea of a cone which has been conveyed is that of a single figure with a circular base and pointed apex, like the spire of a church, while, as it might be said, a complete cone is double, like an hour-glass. This, no doubt, is so, but as we have been concerned with the parabola only, a curve which has to do with the section of a cone made wholly on one side of the apex, it was not thought worth while to encumber the text with details which were practically unnecessary.

It may be mentioned that anyone who desires to see a parabola in the flesh, if that expression may be used to signify its visible personality, may generate the figure in question by putting on a flat table a lamp whose flame is just on a level with the top of an upright

hoop placed alongside of it. The shadow whose head will be found to touch the point on which the hoop stands will be a parabola.

The reason why a ball rolls when despatched along a surface claims examination, but it will be more convenient that this matter should be looked into presently when we come to consider the motions of a hoop.



CHAPTER IX.



THE Kaleidoscope, to which we will now turn, is one of the youngest of toys. It was invented by Sir David Brewster about 50 years ago. The principle, however, on which it is founded was not new, since it must have been then, as it is at this day, exemplified in almost every drawing-room, that is to say in every room which happens to have two mirrors opposite to one another on different walls. It cannot fail to be noticed that whenever this arrangement exists any object intervening between the two glasses so as to be reflected in them, is repeated an indefinite number of times in both. To take, as an example, a prominent and noticeable object by which the effect in question is most strikingly presented, namely, a chandelier with lighted candles. This, when hanging in the intermediate space between the mirrors, will produce in each of them a long vista of illumination, extending seemingly throughout an interminable chamber, like the Burlington Arcade continued out into infinite space, to which the room will to all appearance have stretched itself.

The multiplication of the lights in the manner which

is thus witnessed takes place in the usual and necessary course of reflection by common mirrors. For when you look at yourself in a looking-glass you see a "counterfeit presentment" of your own face, together with as much more of your personality as the area of the glass is large enough to display. If you approach the glass more nearly, your "double" approaches also, and if you recede from it your other self does likewise. Your image, therefore, to all visual intents and purposes, is your own self, placed at exactly the same distance behind the glass as you in fact stand before it.

If a second mirror be now set parallel to the first, but behind you, it will be bound to show, first of all, the direct reflection of your person, and you will appear to be as much removed to the back of the glass as you are, in truth, from its front. But to the perceptions of this second mirror your image reflected in the first mirror is for all practical purposes another real and bodily version of you, only a little farther off, inasmuch as the surface of the first mirror is more remote from the surface of the second mirror than you are. This image, therefore, takes its place in the second mirror at some point or other behind the one which is already there. This second image in its turn becomes virtually, as far as the first mirror is concerned, an original, and is accepted and represented by it as such, taking, when this occurs, a position which may readily be determined by anyone who, like the glass, exercises a little reflection.

We thus get by repeated reflections an indefinite number of images in each mirror. The series would, of

course, be absolutely infinite were it not that reflection, like everything else in this world, is more or less imperfect, so that on each occasion when it takes place a certain amount of light is lost. Hence each succeeding image is fainter than its predecessor, till at last the series fades away through increasingly dim stages into nothingness. Standing between the mirrors you would not be able to behold yourself thus multiplied, since the foremost image in each glass would interrupt the view from your position of the figures behind it, but any one looking downwards from the ceiling would see the effects described.

A double series of images such as has been mentioned may be called into being by the easy expedient of holding or fixing two looking-glasses vertically on their edges parallel to and facing one another. Place any object which may be at hand, a bright one for choice, between them, and it will be immediately reproduced, as has been predicted, in two long trains of semblances of itself extending on either side into dim vacuity. Now bring either the upper or the farther edges of the mirrors nearer to one another, and observe the result. The two lines of images curl, as will be noticed, in the former case upwards, and in the latter horizontally, till at length they unite and form a complete ring. This circle will be found to be one whose centre is at the point where the mirrors meet, and whose radius is the distance from that centre of the object which generates the images. Why it is that a circular series of images is obtained by the arrangement described ought not, after what has been said, to be a riddle difficult of solution.

Now suppose that it is wished to keep the mirrors fixed in some given position with reference to one another, say with their upper edges in contact, and with their reflecting surfaces inclined to one another at a particular angle which has been found to conduce to the best optical effects, and which is therefore desirable to preserve. The most convenient mode of giving assured permanency to any successful arrangement of the mirrors which may have been lighted on will be by surrounding them with a stiff tube, and fastening them into it in their existing positions. Instead of continually changing the object for the purpose of giving variety to the spectacles which the mirrors are to display, it will be less troublesome to close in the end of the tube which is to be farthest from the eye with two discs of glass parallel to one another and just far enough apart to form a shallow box in which may be placed some small loose bits of any coloured material which will of their own accord tumble at haphazard into different modes of arrangement as the cylinder is turned round. The glass which forms the inner side of the box should of course be clear. That on the outside should be of ground glass, so as to be translucent, but not transparent. It will thus admit light to the tube, while preventing any view of external objects from mingling with that of the coloured scraps. Finally, let the end of the tube which is nearest the eye be shut in with any opaque substance having a hole in the middle sufficiently large to be conveniently looked through. A kaleidoscope has now been manufactured. Of course, for practical convenience, it will be expedient to use

long strips of silvered glass, instead of looking-glasses, as mirrors.

On looking through the eye-hole, the coloured scraps are seen arranged apparently in a circle, so that they form an orderly pattern which successfully personates design. No one can have failed to remark the optical effect of reflection in still water. The real object or scene which is mirrored, however irregular and ragged in outline it may be, acquires, when conjoined with its reversed image, which it meets at the surface of the pool, the character of a symmetrical and well-balanced picture, inasmuch as similar figures are disposed in an order which, although reversed, is still one of exact correspondence, on either side of a particular dividing line. In the kaleidoscope, the outline at any given moment of the little pile of coloured scraps, and the internal arrangement of its component items which at the same time prevails, represent the state of things brought about by the last preceding revolution of the cylinder, and as far as the person who is using the instrument is concerned, are entirely unforeseen and accidental. It is altogether owing to the reduplication of the composite pictures which are generated by the union through reflection of image with reality that a continuous and complete pattern is due.

Whoever desires to understand a kaleidoscope should make one, since this may be done at an insignificant cost both of time and money. Various points which cannot be dwelt upon here will then present themselves to notice, one of which will be the following. The angle at which the mirrors are inclined to

one another must be some aliquot part of 360 degrees, and the number of the images formed will depend on the size of this angle. The larger the angle, the smaller will be the number of images. If, when the kaleidoscope is in action, a pattern happens to be presented which is exceptionally beautiful, and therefore worth preserving by means of a copy, the instrument must be kept perfectly still until the design has been transferred to paper. For the variety of mosaic designs which even a couple of dozen, or a less number, of fragments of coloured glass suffice to form by the different modes of combination of which they are susceptible is, practically speaking, infinite. It is therefore no romance, but a mere dry and simple mathematical truth, which any one possessing an acquaintance with elementary arithmetic can readily verify, to say that a kaleidoscope containing no more than, say, 20 of such bits in its terminal chamber might be kept continually turning for ages, before, according to a strict estimate of probabilities, any pattern which had once come upon the scene would be likely to recur.

The observation which is applicable to almost every toy, that it will admit of expansion and improvement till it becomes a source of a variety of instructive and interesting effects, is especially true of the kaleidoscope. By a suitable modification of the tube the glass box may be dispensed with, and instead of the coloured fragments, which, with all their capability for entering into fresh combinations produce nevertheless a certain sameness of general effect, external objects may be brought into the field of view. If these be in motion, such as trees blown by the wind, or carriages, or waves

of the sea, an endless variety of self-shifting, curious, and amusing designs will be presented to the eye. More brilliant effects, also, than those which are witnessed in ordinary kaleidoscopes are procurable by substituting for the mirrors a prism of clear and un-silvered glass. This will be so for a reason which must be given at some length.

It was mentioned just now that on every occasion when light is reflected there is some loss on the transaction. A certain percentage of the rays which fall on any surface are dissipated irregularly, ("scattered," as it is called,) or else absorbed. The waste which always occurs in this manner is greater or less in proportion to the degree of reflecting power which the surface in question happens to possess. Even in the case of reflecting telescopes, where the speculum or mirror is the very best thing of the kind which human labour and skill can produce, and where expense of construction is, in the too familiar, though vulgar and confused, phrase of the Servants' Hall, "no object," nearly 50 per cent. of the light which falls upon the reflector is lost. If a mirror did its work completely, that is to say, if it honestly repaid all that it receives in the way of light up to the uttermost beam, it would be itself invisible. It would present to the eye nothing but an absolutely perfect counterfeit presentment of nature in an extremely vivid picture of the objects whose images falling upon its surface were reflected thence to the eye of the spectator. A looking-glass, though for ordinary purposes the most convenient form of mirror, is not only a reckless spendthrift of light, but does its business of reflection in a confused and

imperfect manner, which, if our perceptions were more keen and delicate than they are, would be uncomfortably manifest and annoying. You will discern why this is so if you bear in mind that a main part of the work of reflecting is done by the amalgam of quicksilver and tin with which the back of the mirror is coated.

It may be observed here by way of parenthesis that the idea of the employment of polished metal as a reflector may seem to have some sort of impression of novelty about it, but next in time to clear pools, such as Eve must have done her hair by, and which were the first looking-glasses, came metal reflectors. Those made by the ancients were, of course, functionaries of a far simpler and less efficient order than the brilliant implements composed, usually, of copper and tin, with, sometimes, the addition of other metallic ingredients, which modern astronomers have enlisted in their service. Glass mirrors are, in point of date, mere institutions of yesterday as compared with metal ones. Now a plate of polished metal, even if it be in itself absolutely perfect as a mirror, will be seriously impaired in efficiency if a screen of not altogether complete transparency be interposed between it and the objects which it is set to reflect. If, for example, it be plunged into clear water, some of the rays which would otherwise have fallen upon it will be reflected by the fluid, and will mingle confusedly with those which are on their way to and from it. Besides which, the light which is not summarily turned back by the water will, both in coming and going, be attenuated in quantity, and diverted from its proper track, by absorption and refrac-

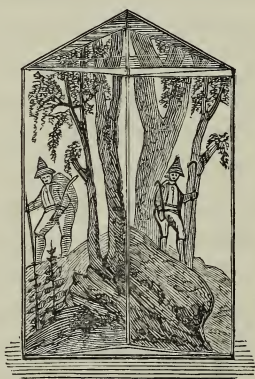
tion. The behaviour of a glass mirror is prejudicially affected by circumstances which are of a nature exactly similar to those which have been just supposed.

It is, no doubt, true that in spite of the defects which have been adverted to glass specula are used, and are perhaps even to be preferred, on the whole, to metal ones for telescopes, but this is for special reasons which are as follows. The face of such a mirror, of whatever substance it may be composed, must, as need scarcely be said, be kept scrupulously bright and clean. A speculum, like a lady's reputation, leaves everything to be desired unless it be absolutely spotless. But it is found that the brilliancy of a metal one cannot be preserved for more than two years without scouring. In cold weather, too, there is constant condensation and freezing upon it of the moisture of the air, rendering it too dim for use unless it be frequently wiped. It is, however, hardly possible to rub a mirror which is wholly composed of metal without putting it a little out of its true shape, or generating undulations or depressions in its surface, thus vitiating the accuracy, and, as a consequence, largely reducing the value of the images which it presents. To this inconvenience is to be added that a metal speculum must be immensely massive, for otherwise it is likely to bend of itself, in which case it would give distorted images. Metal of the kind required is also most difficult to work, being so brittle that it constantly breaks without the least provocation.

Glass does not suffer disarrangement of contour to anything like a similar degree under polishing; it has also more stiffness of natural constitution, and

is easy to manufacture. It has moreover the great virtue of maintaining what may be called an imperturbable smoothness of countenance, and is therefore serviceable as a facing. Its vocation is, of course, merely that of acting as a framework to support the true and sole reflecting surface, which is the polished silver at the back. All things considered, perhaps the best form of speculum is that of a fabric of glass coated in front with a very thin layer of polished silver.

Now glass, as everybody knows, will, under certain conditions, act as a mirror without being backed by amalgam. The ghost at the Polytechnic, for example, did not, like other ghosts, owe his existence simply to the credulity which belongs to want of education, but to a contrivance of which a sheet of clear glass, adjusted to a particular angle with reference to the spectators,



was a main feature. Two reflectors of plain glass without any metal backing, one of them a flat disc, and the other a rectangular prism, form part of the accoutrements of every good microscope. In a pretty

drawing-room ornament which has lately become common, a figure is painted on one of the facets only of a glass prism, but to a spectator viewing the thing from a particular angle of view the picture is seen in duplicate, reflection supplying a second image which is indistinguishable from the first one.

A prism which is to be employed as a reflector must be shaped as follows. One of its corners must be a right angle, or must be one of not less than about 83 degrees, and the sides inclosing this must be equal to one another in length. Light allowed to enter such a prism as this through one of its two equal sides, and to fall upon the third, which will be the longest of the three, will be dispatched by reflection from this last outwards through the remaining member of the trio. The contrivance for copying drawings which must be familiar to you as a popular toy, is founded on this faculty for reflection which plain glass, when suitably adjusted, possesses. The drawing which is to be copied, and the sheet on which it is to be reproduced, are laid flat on their backs alongside of one another, and a plate of glass is fixed vertically between them. It will be seen at a glance how, by taking advantage of the light-transmitting and reflecting faculties of glass at the same time the making of the required copy becomes a mere process of tracing.

An account of the effect which is witnessed in all these cases may be very roughly and generally given as follows. Light falling with no more than a certain degree of obliquity on a flat piece of glass, passes through it and emerges at the other side, bent out of its original course in a manner which is called refraction.

But if the slant with which it falls upon the glass have more than a given inclination, or, as it is expressed, if the line of incidence make a greater angle than one which is called the "critical," or "limiting" angle with a perpendicular drawn to the surface which is met, then reflection instead of refraction takes place. This limiting angle varies with the greater or less refractive power of the medium through which the light passes.

A tumbler of water with a spoon in it will exhibit the phenomenon of reflection substituting itself for refraction under such conditions as have been mentioned. For when the tumbler is held high enough to enable a spectator to look up to the surface of the water from below, the spoon will be seen reflected by the interior face of the flat ceiling of the liquid in that direction. The vividness of the mirrored image will be striking, and this circumstance will of itself suggest what is in fact true as a general rule, namely, that reflection takes place with the most economy of light, and therefore in the most efficient manner, when it occurs within the medium through which the rays pass. Hence it becomes apparent why a glass prism might be advantageously substituted for the mirrors in a kaleidoscope, since the brilliancy of the optical effects would be thereby much enhanced. Prisms, therefore, would no doubt be used if expense could be disregarded, but the ordinary mirrors are preferred for their cheapness.



CHAPTER X.

TOPS are the most interesting of all toys. It would be a pleasant occupation for anyone who had the time to spare, to trace their history. As a proof of their antiquity it may be mentioned that they were popular with the Romans as many, at all events, as 18 or 19 centuries ago, and probably much earlier still. Virgil, who wrote most of his poems about the time of the birth of Christ, describes a party of youths entertaining themselves by keeping a whipping-top spinning. The passage in the *Æneid* in which the scene is depicted is familiar enough to every schoolboy. Tops are also referred to by Juvenal, and by Persius, who both speak of them as if they were old and favourite institutions. The Japanese, whose civilization, though not of the same pattern as ours, is very ancient, are great lovers of tops, and make them spin and go through all sorts of performances with a docility, precision, and even a seeming intelligence, which the less adroit and delicate touch of the finger-tips grown in this quarter of the globe quite fails to impart. A top, therefore, is one thing to a Japanese, and another to

an Englishman : similarly, to an ignorant person it is but a toy, while to an educated mind it is no mere plaything only, but an instrument by which the working of some of the most important laws in Astronomy and physical science is strikingly illustrated. The present Astronomer Royal has somewhere or other pointed out the claims which a top thus possesses to attention. Mr. Herbert Spencer, also, in his "First Principles," dwells upon the various phenomena exhibited in the spinning of a top as aiding to elucidate particular points in the general order of creation.

Thus much having been premised for the purpose of bespeaking your careful and serious attention, let us spin a top, and see what occurrences ensue which are noteworthy. Regarding the space of time during which it spins as its period of vitality, or, in other words, as being, for the top, a lifetime, what may be called its early youth, when it first assumes the character of an animated being, is one of vehement and tempestuous action. Under the gentle and persuasive, but efficient, impulse which a Japanese manipulator imparts, this is not so, since a top, if set going by a competent artist, never bounces about, but devotes its whole energies to its proper business of spinning. But when it is started by a maladroit operator, it generally begins by hopping and dashing excitedly over the surface on which it is set going, and bumping itself against any sides inclosing that arena which it can manage to reach, like a lively bluebottle fly caught under a tumbler. Having sowed its wild oats by thus extravagantly squandering much of its endowment of vital energy, it waltzes round and round with a reeling

motion, which is gradually toned down into a demeanour of more and more composure, till at last it becomes stationary and upright, and spins tranquilly for some while in that position. Eventually, a tremulous motion discloses itself, which, becoming aggravated, develops into a wobble of a more and more pronounced kind, till at last, in one of the lurches which supervene, the body of the top scrapes against the floor. Spasms of vehement action now set in, during which the top bangs about on its side. These are soon exhausted, and at their close the top lies still and dead. What have been the several motives of the successive phases of conduct which have been described, and with which we are so familiar?

To begin with the first. The top is set spinning by imparting to its axle a brisk movement of revolution by means of the uncoiling of a string wound upon it for this purpose. The person who spins the top giving a necessarily hard pull at the string with his right hand, must resist this tug by means of the handle which he holds in his left, for otherwise the top, of course, would be drawn away bodily from the locality where it is to be set going. Ultimately, when the inside end of the coil of string leaves the axle, the pull exerted by the right hand suddenly ceases. If the counteracting force applied through the handle be not relaxed and discontinued in precise correspondence with the diminution and cessation of its opponent's effort, which is a very difficult thing to adjust, the top, at the moment when it is released from the tutelage of its controlling appliances, receives an unintended impulse which contributes nothing to its spinning, and which

carries it bodily in some lateral direction across the surface of the arena where its performance is to take place. This movement of translation is opposed by two forces, one of which, the resistance of the air, is in this case so trifling that it is not worth consideration. The other, which is that which really, and very soon, arrests the movement in question is the friction of the point of the peg on which the top spins against the surface over which it travels. Friction being persistent and inexhaustible, and the force to which the travelling just spoken of is due being of only finite quantity, the destruction of the latter by the former agency is necessarily a question of time only, and whenever this consummation is reached, the top comes to anchor at one spot.

Here, it presents phenomena of movement of a new kind, since it is observed to wave, as it were, its axle in circles, thus, as upon consideration will be manifest, describing in the air the surfaces of mathematical cones. The apex of all such cones is, of course, at the point upon which the top spins. These circles are at first large, the inclination of the axle diverging by a large angle from the perpendicular, so that its upper end points to the walls, perhaps, of the room, or at any rate to the exterior suburbs of the ceiling. The circles gradually shrink, the axle describing, in real truth, a spiral. The limit of convolution is ultimately reached when the angle which the axle makes with the perpendicular vanishes, and the top then spins with so smooth and imperceptible a motion, a "motionless motion" as one might call it, that it is said, in the popular phrase, to be "asleep." The French describe this condition

of things in which the result of the action of dynamical forces, that is to say, of forces producing motion, is stillness, such as that of a sleeping top, by the expression "equilibrium mobile."

But "Why," it may be asked, "will not the axle of the top rest satisfied with any other than a vertical position? That is to say, suppose the top were to be started with its axle pointing at some one particular corner of the room, why should not this attitude be contentedly maintained?" The reply is that if the top were left to follow exclusively the bent imparted to it by the forces with which it is animated when it is first set spinning, it would continue in the pose which is just assumed, and not by a mere passive acquiescence only, for that under the influences dominating its movements it would resist the disturbance of that attitude. This would be the case under the general law which is found to hold good, that the axis of any rotating body has a strong disposition to permanency. If a quoit is thrown, it is purposely made to revolve as it flies by a twirl given to it at the moment when it is dispatched upon its errand, so that its behaviour is suggestive of a wheel running one way but carried another. The spinning tends to keep the quoit in one attitude throughout its whole course, and thus to render its flight more true than it would be if it wobbled. Saturn's ring (or rings, for it is a double one), which preserves the same unchanging attitude as it circles through space, illustrates on a grand scale the characteristic faculty which a spinning quoit presents of retaining the same pose throughout its flight. The result is in each case due to the same cause.

Just now, as you will remember, we had occasion to inquire why it is that arrows, rifle-balls, and other missiles, are made to spin. One advantage to be gained by causing them to do so was then marked, and a second has now come in view. For the spinning, as tending to impart constancy of attitude to the axis, promotes, of course, the result of keeping the projectile in the way it should go. The effect of revolution on an axis is illustrated by a child's hoop, which is kept by this means from falling as long as it continues to be possessed of some tolerable quantity of rolling motion. It is also strikingly witnessed in the proceedings of the gyroscope. In the gyroscope, when it is put in action, the movement of revolution, as long as it is imbued with a considerable degree of vigour, has so much determination to keep its axis in its existing position for the time being, whatever that may be, that it is capable of maintaining a heavy brass ring, which is otherwise unsupported, in a horizontal position, or inclined at some angle to the perpendicular. There is a trite quotation,

“The very law that moulds a tear
And bids it trickle from its source,
That law preserves the Earth a sphere,
And guides the planets in their course.”

The lines would apply to a multitude of other cases in the sense of conveying the remark that King Law's sceptre is wielded over a vast crowd of subjects, big and small, but that all of them alike conform with loyal and scrupulous exactitude to the ordinances established within his dominions.

The permanence of an axis of rotation is an in-

stance of a rule governing matters of extremely varied dimensions, since the phenomenon in question, while it is exemplified by the movements of a top, a quoit, a shuttlecock, and a thousand other toys, is illustrated by a working diagram on a larger scale, but not a bit better, by the preservation of the attitude of the line joining the North with the South Pole as our globe rushes through space. The same result of forces producing motion, or dynamical effect, as it is called, which keeps a hoop erect when rolling, and thus endues it with the charm which it possesses for Master Tommy, (since if it did not go tolerably upright it could not be trundled,) gives, as another of its effects, the four seasons, Spring, Summer, Autumn, and Winter. If tops should cease to stand upright when in full spin, great changes, revolutionizing the general order of creation as now established, must occur at the same time; for should the Earth's axis lose its conservatism of posture, one of the consequences which cannot but at once ensue will be this, that our summers will be colder than our winters, since, as most people know, we are farther from the Sun at midsummer than we are at Christmas. All this will be thoroughly understood before the end of the first half-hour which is devoted to making acquaintance with elementary Astronomy.

From what has been said, it is clear that a top, if set to spin rapidly, and if its behaviour were not affected by any influences other than those which have been hitherto noticed, would retain, until its speed flagged, the posture assumed at its first start. But it does as a matter of fact raise itself to a vertical position

in spite of the opposition of gravity, and of the forcible inducements to maintain an unaltered trim which its spinning, as has been seen, creates. An answer to the riddle here presented for solution is to be looked for at the tip of the peg on which the top spins. If there were no friction at the point of contact of the tip with the surface on which it rests, the top would not raise itself to an erect position at all. But there never is, and cannot be, either a point or a surface so constituted as that there will not be a grinding action between them where they meet, if either of them is in motion and the other not so. Look at a fine needle through a microscope of even but low power, and it is seen to be a rough barge pole in miniature, and correspondingly blunt. How it is that friction exerted by the motion of the tip at the point in question has the effect of causing the axis of the top to become erect is a problem of some little intricacy, requiring a deliberate as well as a close attention, which could not expediently be bestowed upon it at this moment. The whereabouts of the key to this question will be sufficiently indicated to those who may desire to hunt it up by directing attention to the fact, that whenever the top is not upright it keeps rolling round, like a skater doing the outside edge, upon a rim of its tip.

We have thus watched our top, after its initial period of excitement and irregularity, becoming stationary on one spot, and then brandishing, as it were, its axle in continually diminishing curves, which, if they could make their mark upon paper, would be like those of a Catherine wheel, till at last on reaching their centre, or nucleus, no farther convolution remains possible ;

and we have seen the top then standing erect, with its central line vertical, and actually divested of all movement except one, which is imperceptible. The complete stillness of the axle, whatever the speed of revolution may be of the body which environs it, whether this be a top, or anything else, reminds one of the picturesque expression which Tennyson uses of "the whirlwind's eye of calm," alluding to the circular sweep of cyclones, eddying as they do, after the fashion which their name indicates, round a nucleus of undisturbed tranquillity. The analogy is strengthened by the circumstance that the same Latin word "turbo" stands both for top, the typical representative of a spinning object, and for whirlwind.

The top having raised itself to the full height which its stature permits, and poising itself on tiptoe, "equilibrium mobile" is now established of such perfect quietude as to simulate the inertness of sleep. But if the top be suitably constructed, it will be by no means lifeless, but will betray its veiled activity by its hum. Here arises another question to be looked into. Of what nature are the vocal organs of the top by which it sings its own peculiar and monotonous song? If we were to spend as much time upon this subject as would be required to do it proper justice, we should get but little change out of a whole evening. In this, therefore, as in so many other cases which we have been obliged, for like reasons, to treat in a similarly incomplete manner, it must suffice to hint the general nature of the answer, leaving the details to be ascertained by any enterprising inquirer.

What we call sound is our perception, through our

ears, of rapid vibrations. These are usually those of air, though the quivering motion is more perfectly conveyed by other substances. The stethoscope, for example, an instrument used for the medical examination of people's chests, is a wooden tube which catches sounds which, without its intervention, would not be audible, and transmits them, with great fulness, delicacy, and clearness, as thrills, running along its own person, to the ear of the listener. The pitch of any note depends exclusively on the rapidity of these vibrations; that is to say, the greater the number of them which take place within any given period of time, as, for example, a second, the higher the note. Such vibrations may be properly regarded and spoken of as waves, since they behave as such, and sound will be rightly understood if it be considered as a ripple. A ripple of water is, indeed, confined to one plane, that is to say, it takes place along one flat surface only, while billows of sound are spherical, that is, are propelled in all directions from their origin, like rays of light from a star. But this point of difference between the two cases may be quite disregarded as far as the purposes of the present moment are concerned.

Sound, then, being viewed as a ripple, it will be true that the shorter the waves, that is to say, the greater the number of them which could be arranged as a series within any given longitudinal space, the higher the pitch of the note which they form. On the other hand, the loudness of any given note, which, as need not be observed, is quite another thing altogether from its pitch, does not depend on the thickness of

the individual waves measured through from back to front, but on their height, or, to put the same thing another way, on the depth of the valley which intervenes between any one of the tiny billows and its next neighbour.

Whatever musical instrument be employed, the notes are, in fact, generated by the same identical means, that is to say, by the production of vibrations, or waves, although the tackle employed for the purpose varies according to the character and quality of the sounds which are wanted. When the piano is played, string after string is set vibrating by a series of blows from little mallets worked from the key-board. A harpist employs the direct agency of his own fingers, and instead of hammering the chords, he plucks them. Wind instruments, also, are simply implements for communicating vibrations to air. It is interesting to note the variety of mechanisms by which the desired result is attained in the several components of an orchestral band, taking as typical examples of different leading methods—say—the trumpet, oboe, drum, harp, flute, and clarionet. To these may be added a home-made and simple imitation of human speaking tackle constructed of two tubes, one of glass, and the other of india rubber. The latter is to be arranged so as to clasp the former very tightly for a short distance of its length at either of its extremities, and should project an inch or so beyond it. By blowing down the glass tube in such a manner as to impart to it a thrill, or shiver, (the knack of accomplishing this is one which cannot be described or taught in words but is only to be learnt by experiment,) sound is produced, and by

then elongating the elastic mouth-piece in varying degrees by stretching it, a very fair imitation of the action and effect of the lips in modulating the voice may be achieved. The organ supplies an example of the creation of notes by more than one method, that is to say, by stopped and by open pipes of peculiar construction. For our present purposes a flute will supply the most appropriate illustration of the generation of sound, since its notes are born of parentage which has a close relationship to that of which the hum of the humming top is the offspring.

A flute, to describe it in its main aspect, is, as everybody knows, a hollow cylinder open at one end and closed at the other, and having near one of its extremities a hole to which the mouth of the player is applied. We need not deal here with the various accessories of the instrument. If we were to do so we should have to include among them, as being the most important of all, the lips of the performer, since these are not mere sources of air, but in reality integral and essential parts, for the time being, of the instrument itself, since it is on their texture, and mode of employment, that the quality of the notes chiefly depends. Hence it is that the tone of one and the same flute is found to vary from that exquisitely limpid clearness which to the sensations of any competent judge is the most delicious sound, as coming nearest to the supreme perfection of the human voice, which can be produced by any musical instrument, but which is extremely rarely heard, down to the usual husky, cold-in-the-head sort of snuffle with which we are all, unhappily, but too familiar.

Now the performer must blow across the hole which has been spoken of, and not into it. When he does so, a wave of air is set going, which runs along the interior of the hollow body of the flute towards its open end, and thence returning, partly interrupts the blast flowing from the lips for an indefinitely short instant of time. This proceeding is constantly repeated, and a series of waves thus going and returning, and eventually issuing from the mouthpiece in the form of small puffs, and vibrations, constitutes sound. Why the mouthpiece should be placed where it is, and how it is that the waves should conduct themselves as has been described, coming back from the open end instead of escaping from it—these, and a number of other phenomena which must be thoroughly studied before the action of a flute can be properly understood, are not such as can be entered upon here. They must perforce be left as mere matters of bare statement.

If a flute were to be made to spin, or to move through the air in any other manner, with sufficient rapidity, which would have to be very great indeed, it would give forth a sound, because, as we had occasion to observe some time back, with reference to a windmill supposed to be carried on a railway train, it is the same thing in effect whether air is in motion and the object on which it acts is at rest, or whether what may be called a reversed counterpart of this arrangement prevails, since in both cases a current, either actual or virtual, is produced. The note uttered by a flute made vocal by the consequence of its own motion would be but a dull monotone, since it would neither be turned out duly clear and fresh, nor could it be inflected, for the lips and mechanical

appliances which are indispensable for giving decisiveness and variety would be wanting. It would be thus, in fact, a simple buzz, or whirring sound.

It has been stated that a flute may be made to speak by putting it into a certain relation with the air about it equivalent to, but not absolutely the same as, that which prevails when it is played in the orthodox manner. Its vocal faculty is hence seen, or may be at any rate surmised, to have the same organization as that of a top. It may be still more readily caused to discourse articulate music by substituting for the lips of a player a vibrating tuning fork, and by executing at the same time the fingering which properly belongs to the note which is thereupon sounded. The secret of the hum of a top now stands revealed.

It is as well to give a word of caution against confusing the droning song of a humming top with that which is heard on applying the ear to a shell. A hasty and erroneous assumption might be made that as a top and a shell seem to the ear to sing the same kind of song, therefore their organs of speech, and sources of voice, are alike, which is not at all the case. A top draws breath, and becomes vocal, through its own motion, in the manner which has been attempted to be described. The note of a shell is a mere tumultuous combination of the echoes of external noises, many of which would be individually too weak and slender to announce themselves separately to our perceptions, human organs of hearing not being sufficiently fine-strung to deal with sounds not possessing a certain degree of strength and fulness. When, however, these external noises become blended by the shell into one

general chorus, they then acquire sufficient body and substance to proclaim their existence, since the tiny waves of which they are severally composed, beating against the drum of the ear in the shape of a general and confused torrent, are thence translated to the brain, which is the real seat of hearing, as an undefined and continuous hum. A shell "roars," as it is expressed, in this way because it possesses in an eminent degree the faculty of resonance, that is to say, the conformation and texture of its interior surface happens to be such as to render it intensely responsive to sound.

Nature, who is a skilled artificer of much resource, has availed herself, in the formation of the human organs of speech and hearing, of all the principles found serviceable in the construction of the musical instruments which have been named this evening, but with far more efficient and delicate modes of application. Being thus, as might be expected, aware of the faculty of resonance with which shells are gifted, she has turned it to account in the structure of the ear, for we find that what is called the "cochlea," or "shell," is an important constituent of our arrangements for hearing. There is an odd conception which children and amusingly ignorant people entertain, that the hum of a shell resides in some way or other within its chambers. They have a hazy sort of notion that the roar of the ocean in which, as they suppose, the fish who was lately occupier of the tiny marine villa which is now hollow and echoing passed his existence—(he may probably have lived in depths which were still and silent enough)—became so inveterate a frequenter of his premises as to continue to haunt them after his decease, and when far removed

from winds and waves. This theory is put out of Court by the fact, which is easily substantiated by experiment, that any object which happens to have by means of its form, and the mechanical conditions of its substance, a special faculty for yielding resonant echo, will roar vivaciously, although it may have been always inland.

Ear-trumpets, such as deaf people use, act to a great extent in the same manner as shells by reflecting and concentrating sound. They are not properly to be regarded as the converse of speaking trumpets, since they are the very same things, only that as their purpose is of a different kind their shape and mode of employment is appropriately, but slightly, varied. It will be remarked that ever so loud a sound does not produce a blast like that from a military trumpet in a deaf person's ear. It would be highly inconvenient if it did so; and there are two reasons why no such effect takes place. One of these is that such a note is not produced, or producible, by mere sound, that is to say, by air in motion, however energetic. A trumpeter by means of his lips sets the metal substance of the trumpet vibrating in concert and conjunction with the pulse of the column of air which gives the note, thus intensifying its motion and effect. Without the thrill which must be imparted to the instrument by the lips through direct contact between it and them, the note of a trumpet or of any wind instrument cannot, as a general rule to which the exceptions are limited, be generated with either the body, strength, or precision which are all of the very essence of its being. It will be observed, moreover, that by blowing through the mouthpiece of a trumpet the whole effect, whatever it may be, of this

act is applied to the instrument. On the other hand, when speaking or shouting takes place at the bellshaped end of a speaking trumpet, many of the vibrations of air escape laterally, or at any rate are not projected through the resonant channel with all the original energy which they may happen to possess.

To return to our top, which is all this time humming in its sleep. Its energy of spinning, and the tendency, which is wholly dependent on that energy, to maintain an erect attitude, are both, slowly perhaps, but surely, undermined by two forces, namely, that of friction at the spot on which the peg stands, and the resistance of the air. In real truth the resistance of the air is as simply friction, and nothing else, as is the grind by the point of the top's peg upon its support. Could, which is practically impossible, a perfect vacuum be formed, that is to say, could air, and everything else which can occupy space, be exhausted from some close chamber, and could, which is also impossible, friction be prevented from occurring at the tip of the toe on which the top pirouettes, the spinning would literally go on throughout all eternity, for there would then be no reason why it should ever stop. The supposition that it either would, or could, come to any end, except under compulsion, is fully as inconceivable as that of its commencing of its own accord, since both of such proceedings would equally imply the exercise of spontaneous action on the part of the top, that is to say, the possession on the part of a piece of wood of an independent will of its own, and of a muscular apparatus capable of giving effect to mental impulses.

We spoke some time ago of what is called "vis

inertiæ," meaning the indisposition on the part of any object to move unless under the impulse of some external force. The fact seems to be usually overlooked, or taken less account of than it should be, that the vis inertiae continues with unimpaired effect when the repose of the object in question is broken, and motion is substituted for quiescence. For the moving thing still retains its quality of inertness quite undiminished, that is to say, it is as passively disposed as ever, and thus has no sort of tendency either to increase the speed with which it is now endued, or to relax it, except, as has been stated, under the action of some external force. Not voluntarily stopping, therefore, but when the life of its impetus has wasted itself in battle with enemies, the top becomes gradually amenable to the attraction of gravity only. This force, endeavouring, as is its wont, to lay things as low as they can go, aggravates each of the slight, and at first imperceptible, declinations from the exact perpendicular which small disturbing influences, such as the irregular action of currents of air, and of friction, are sufficient to cause. The power on the part of the axle of the top of recovering an erect posture is enfeebled more and more by every such strain on its supports. The operation of these occult influences is first declared by a momentary dip on one side or the other which is shortly afterwards repeated in the aggravated form of a resolute "duck" downwards. Presently the axle becomes altogether tottering, and eventually a dive is made which is deep enough to allow some point of the under side of the body of the top to graze the ground. The force of friction which is generated by the collision instantly

engages in violent conflict with such of the spinning motion as yet survives, and in the short, but sharp, contest which ensues the top is carried hither and thither in convulsive throes, till it comes to rest on its side, still, and inanimate.

It lies, as has been said, altogether lifeless, but this does not imply that its inertia is the result of the suspension or destruction of all agencies tending to produce motion. By no means. The top is at this moment fully as much "a creature of impulse" as it was when in full spin. If caused to poise on the tip of its peg, but without revolving, it is in a position of what is called "unstable equilibrium," for although the result of the forces which control it is such as to produce rest for the moment, the mutual adjustment of these agencies is of a kind which not only does not recover itself if ever so little disturbed, but has a tendency to produce still further motion. Sleeping on the point of its peg, it is in a position of temporarily stable balance, its quiescence of attitude being due to forces which, while producing a motion of its parts round its axis, do not cause, or favour, but oppose, any transference of its mass as a whole from one posture or place to another. A state such as this, is, as has been said, one of what the French call "equilibrium mobile," or "kinetic stability," as it is sometimes termed with us. Lying on its side, the top is in a position of what may be termed "neutral" equilibrium, since its rest is permanent until broken by the entry on the scene of some altogether new force. When this event occurs, as, for example, if it is rolled along the floor, the recumbent top yields itself passively to compulsion, but when

relieved from the control of this fresh power, it is not impelled to move farther, or to reinstate itself in its original place.

There is not, however, in its present condition or, as far as we know or believe, in that of anything anywhere in the Universe, either now, or since Time was, or will there ever be till Time ends, real and absolute rest, in the sense of the cessation of all forces tending to produce motion. The repose which the top now exhibits is merely the result and sign of a balance between certain pressures having been set up. The top is giving what may be regarded as a sustained blow upon the floor, since the pressure exerted by its weight is a push, and a push is a more or less protracted stroke. Or if this view of the situation be found difficult of apprehension, it may be said that the top is doing, by the pressure of its weight, what is equivalent to giving a continued series of infinitely small knocks upon its point of support. If the weather were hot, and the top were of butter, so that it had no fixed rigidity of form, the presence of the forces which are in action upon it would stand revealed. For its body and peg would subside into a mere lump. But this alteration of form would not, as you know, be automatic, but could only be due to active external agencies.

The observation which was accidentally called forth that complete quiescence, in the sense of the establishment of an armistice between various contending forces, such as gravity, and others, which are unremittingly at work throughout Creation, is a state which is unknown, as far as we can tell, to the material Universe which

surrounds us, may be made more full, and you will not grudge the bestowal of a moment on the reflections which it occasions, although these are not directed to any question which is immediately before us.

It was remarked that the stillness of a top whose span, or spin, of life is over does not indicate that its person has ceased to be the bone of contention to warring forces, but merely that a balance of a stable nature has become established between the antagonisms which are still at work upon it, and that absence of motion is the consequent result. This quietude, as it may be well to repeat yet once more, in order that the statement may be pushed well home to attention and remembrance, does not by any means show or imply that the strife of unseen agencies has ceased, but merely that these have come, as it were, to a position of deadlock. Not only, it may be added, does the activity of the multitudinous hosts of forces which are at work throughout the Universe never fail or intermit, but actual motion, so far as we can see or conjecture, never ceases for one instant in even a single particle of matter in the most retired and remote corner of the whole domains of illimitable space.

What, for example, is the leading type and symbol of everlasting rest, and immobility, according to popular notions? If an inventory were to be taken of Nature's furniture, a mountain would certainly be put down among the substantial fixtures. To our perceptions, no doubt, it is a sedate object enough, sitting composedly, as is natural to people of the fat habit of body which distinguishes it, on its broad and fixed base. But could we examine it closely, we should assuredly find that it

is endued with an abundance of what is called molecular motion, that is to say, that its every atom is in ceaseless and energetic vibration, and not only that, but unrestingly shifting its position. There is abundant evidence of the clearest kind that motion of this sort is never suspended, although the distance traversed by the particles in their journeys are too minute to be appreciable by the human eye. So much for the parts. As for the mass as a whole, it is, as we know, scudding round the Sun upon the Earth, on which it is set like a stud. Moreover it whirls round the Earth's axis as well as progresses in the terrestrial orbit.

It may have, and no doubt has, countless other motions. For our Sun has been detected to be a mere planet, who, with, of course, the whole attendant solar system, revolves, probably, round a certain Pleiad called Alcyone, one of the stars in the Milky Way. We conjecture this to be the case, because if there be anything whatever in the Universe, which, as far as our perceptions enable us to judge, is fixed, it is the star which has just been mentioned. It is thought that our Sun with his attendant satellites circles round Alcyone, and that he takes about eighteen million years to complete the "grand tour." However that may be, it has been proved to absolute demonstration that our Sun is not rooted to one spot, as was formerly believed. He, and with him, ourselves, are all bound for a point in the constellation Hercules, towards which, if Sir J. Herschel is to be believed, we progress at the rate of about four hundred and twenty-two thousand miles a day. If, as is probably the case, Alcyone, though its motion is beyond our ken, is, in real truth, a mere planet, like our

Earth, the sun round which it revolves is some stupendous globe so immeasurably remote from us that the most vigorously excursive imagination gets spent and wing-weary in the abortive attempt either to reach or picture it. And this great star, again, is, as likely as not, a mere subordinate member of some larger system of celestial bodies, and is dominated by some one individual of a series of gigantic orbs whose distances and vastness are such that the mind gains nothing more by an attempt to bring them within the range of definite conception than a general sense of mere bewilderment and fatigue.

We have thus no reason to suppose that there is anything in the universe which continues in one and the same station. As far indeed as we can infer from the knowledge which we possess, it is not likely that the order of Creation, being such as it appears to be, permits a single one of the unnumbered multitude of stars which crowd our sky, or of those which, as it may be, people the abysses of boundless Space beyond with thronging millions upon millions which, as being endless, no figures could count, to halt for one instant. Gravitation, to whose range of influence there are no known or conceivable limits, would, if it were not counteracted by motion, as it is, in the case of the Earth, by our planet's waltz round the Sun, instantly disorganize the whole arrangement of the heavenly hosts, drawing them together, and eventually pounding them up against one another in a grand general *mêlée* and collision, after which the fragments would be burnt up by the heat generated by the clash. If however the Tory-like characteristic of absolute immobility could with any sort of plausible reason be attributed to even a single

one of the multitudinous denizens of space, such an orb would still present no exception to the general stir which seems to pervade the Universe, unless, in addition to its permanent tenancy of one and the same particular location, it were also devoid of revolution on its axis, and remained, moreover, in one unchanging attitude, and with no alteration in the disposition of its component parts.

The truth thus comes into view that rest can mean nothing more than that the body which is said to be in that condition is merely maintaining an unaltered position and attitude with reference to the person who is describing it. If you go from London by one of the railways which pass through Clapham Junction, it not infrequently happens that as there is a great multiplicity of trains always going by the same route, and in the same direction, you may find yourself in a carriage which is travelling at equal speed with another which is proceeding alongside of yours on a parallel line of rails. To you the other carriage is apparently stock-still, as much so as the interior of the compartment in which you sit, and for the same reason, since, with relation to yourself, there is no change of position. In this limited and relative sense only does rest exist ever or anywhere in the perpetual stir and whirl of the big bit of intricate machinery which we call the Universe.

To return to tops. There is a very convenient form of the toy which is made in the shape of an inverted cap, and has a very short peg to stand upon. It must therefore be poised with the point of the toe of its wooden leg in a shallow hole scooped at the top of a

steady post, so that the edge of its body, or what may be called the skirts of its dress, may not touch the table. It overhangs the top of the post all round, and its centre of gravity being thus below its point of support, the forces to which it is amenable tend as a whole towards the maintenance of its existing upright posture, so that it will balance on its toe not only when spinning, but when quite still, recovering itself after being made to sway in any direction. The stability of its equilibrium is plainly to be accounted for on the same grounds as those on which the balancing on the point of a pin of a cork, when fitted out with two forks, was explained just now. Knowing, as we do, something of the conditions by which the hum of a top is generated, it need hardly be remarked that an open hemisphere, such as that which has just been described, must necessarily be mute. It might easily, however, be rendered vocal, if that were desired, by a slight modification of its form.

Tops are frequently equipped with appliances for the production of "chromatic effects," that is to say for the display of optical phenomena of colours. Small discs of paper coloured in various ways, some irregularly, and some in symmetrical patterns, are supplied for use with a toy of this kind. Each of these is pierced with a hole at its centre, so that it slips readily over the spindle, and rests on the body of the top, whose upper surface is made flat so as to afford suitable accommodation to it, and afterwards to its fellows, which are to be laid in turn one upon another, thus giving a succession of different effects. The top having been set spinning, any disc which is dropped into the place

arranged for its reception acquires at once a similar movement of revolution. This is so because its surface being in contact throughout its whole extent with that of the stage on which it reposes, and which is in rapid motion, its quiescence, or indeed any difference of speed in the revolution of the two bodies which are thus brought together, would be vehemently opposed by friction.

The first disc which happens to come to hand is, we will say, one which is marked with irregular plots of colouring. On dropping it over the spindle, it instantly produces, as will be seen, a brilliant variegated device resembling a rainbow, or target, in general effect, but possibly not constituted of the same hues; or if of the same, not, perhaps, arranged in a similar sequence to that in which they are disposed in either of those objects. The patterns which may be thus displayed in absolutely endless variety, are all, as will be at once understood, due to the persistence of vision which was so fully discussed when the principles with which the zoetrope is concerned were discussed.

You will recollect the cards which were then also examined, furnished, severally, with a device purposely left incomplete on one face, the complementary details being supplied on the other. They were to be spun, as you will remember, in order that the persistence of vision, when thus called into action, might bring to the front the divided halves of each picture in rapid alternation, so that they should coalesce into a perfect whole. The cards in question may be conveniently used in conjunction with a top, for the latter thus imparts the necessary spinning to them. A pin so placed as to

traverse the face of one of the cards and pass across its centre is substituted for the strings used in the former case, and a small portion of the free length of this transverse axis, or axle, for it may be described by either of these terms, which is continued beyond the edge of the material to which it is attached, is inserted in a hollow, or sheath, formed in the head of the top. The mode in which this arrangement acts, and the nature of the results which it accomplishes, are sufficiently obvious.

Like effects, and for similar reasons, are produced by narrow strips of foil, glass, or other stiff material, of designed shapes, for when made to spin by having their lower extremities planted in the crown of the spindle of a revolving top, they represent miniature goblets, or hats, or any other objects of which the opposite sides have a corresponding, though reversed, contour of outline.

In taking leave of the subject of tops it may be remarked that the familiar lines—

“ A primrose by the river's brim
A yellow primrose was to him,
And it was nothing more ”—

would be applicable, in the sense which they are intended to have, to anyone who were to view this toy as a mere simple plaything, easily to be understood, and fit for no better service than that of affording a limited degree of amusement, and that too of a very humble order, to a child. So far is this from being the truth, or anything like it, that a top may be employed in exhibiting a multiplicity of interesting and beautiful experiments in Science. Moreover, anyone who is capable

of giving a really accurate and full elucidation of the secrets which its motions involve must be an astronomer, or at any rate already equipped with much of the knowledge and capacity which go to the making of one. Such a person, for example, would necessarily be competent to elucidate what is called the "Precession of the Equinoxes," a term which reminds one, and not without reason, of "a terrible man with a terrible name" who figures in Southey's "March to Moscow." For the expression, which has a sound which seems to give warning of perplexity, represents a formidable problem of astronomy of considerable importance, but so intractable that even Sir Isaac Newton failed to make it quite clear, and it was not thoroughly explained until after his time.

The celebrated mathematician Euler, who lived about a century ago, devoted a whole book to discussing the motions of tops. He also wrote a treatise on kites. The mention of this latter circumstance is a reminder that kites are awaiting our notice.



CHAPTER XI.

IN the hands of an ingenious and well informed person a kite is a toy which, by suitable adaptations, may be made to do all sorts of things, and among these to talk ;— that is to say, its various modes of behaviour under different circumstances, and under different modifications of its structure, will speak a suggestive and interesting language to those who can construe it. Kites, like the great majority of other common things which are about us in the world, are, as Pindar concisely expresses it, “*φωνᾶντα συνετοῖσι*,” that is to say “have a voice for the wise.” Sir Isaac Newton seems to have gained most of his early lessons in Science from kites.

The first question which naturally arises, that, namely, of why it is that a kite ascends, will be easily solved by the simple process of considering what the forces operating upon its surface are, and then finding what must be the outcome of their simultaneous action, which will be done, of course, by the parallelogram of forces. The use of the tail is to pull down the lower extremity of the backbone of the kite so as

to prevent the head from butting, as it were, against the wind, which it would otherwise inevitably do, for just the same reason, as will be apparent on a moment's consideration, that in a weathercock the point of the vane turns to the breeze. By the drag which the tail exerts the surface of the kite is kept fair to the wind at any desired inclination. It may be mentioned that the best results are produced when the angle made with the wind by the part of the backbone of the kite which is above the point of attachment of the string is one of rather more than 54 degrees. Nobody, probably, would reason with such extravagant unreason as to suppose that the gossamer-like buoyancy of the materials of which the tail is usually composed promotes the ascent of the kite by something of a lifting effect. The tail of a horse, though consisting mostly of hair, and being therefore light in proportion to its bulk, does not help the animal to raise his hind quarters when he wants to kick, and it was not placed where it is found, for any such purpose. The movement upwards of the kite is of course opposed by the downward drag of the weight of the tail. This drawback, however, as we have already seen, is more than compensated by the increased support which the kite derives through being kept in such an attitude that the force of the wind is exerted upon it to the fullest mechanical advantage.

If, as may be asked, the main use of a tail consists simply in its weight, why should not an equivalent in the shape of a bit of lead, scaling at an exactly similar number of ounces or drams, and attached to the bottom of the kite's backbone, or suspended

thence by a string, answer the same purpose quite as well? If it were the habit of a kite to poise motionless in the air, what may be termed the operative element in its tail, or, in other words, its heaviness, might, no doubt, be condensed, as suggested, into the length of an inch or less. But owing to the constant variations in direction and power of the current or currents of air by which a kite is sustained, and to the ever-changing balance of the other forces to which its movements are amenable, its station and attitude alter more or less with every moment. A little observation of the action of the tail will show that this appendage is so constructed as to moderate by a constant and effective, but always temperate and gentle, resistance, any excited behaviour on the part of the kite, with a persuasiveness which answers its purpose much better than the rough correction which a weight jerked and joggling irregularly in the air would apply.

The paper bobs which are arranged in a series along a string, and which form the tail, have in the aggregate a surface which is considerable in itself, and which is very large in proportion to their weight, so that the air exercises no little opposition to their motion in any direction. Owing, also, to their lightness, they acquire no appreciable momentum, which in this case would be a force tending to disorder. Since, however, the resistance on the part of the atmosphere is largely multiplied with every degree of increase of the velocity of a moving object, the drag of the whole tail becomes proportionately heavy as the exigencies of each moment may demand, so that it operates with something like the calculated effect of an elastic spring

so constructed as to deal with varying alternations of pressure with a vigour corresponding in energy with every stress of strain which it may be called upon to encounter.

Kites may be made in an infinity of forms. To determine which kind will fly best would require more consideration than we can bestow upon the question just now. It would be difficult however to improve upon the most popular existing form, that, namely, with the round head, and the body tapering down into a point, for the adoption of this figure is based upon sound principles which will become apparent upon a little consideration.

Whatever the kite may be in its own person, much will depend on the right selection of the exact point where the string is to be attached to it. If this be not successfully hit, the kite will either exhibit a dull listlessness in ascending, or will perform wild and undignified antics by diving, or whirling round and round, like an acrobat turning somersaults, and may eventually, perhaps, put a suicidal end to its own existence by plunging downwards upon its head, and snapping the bow of its frame. The precise situation of the critical point in question, which thus becomes so necessary to be ascertained, will be readily determined by experiment. In the first instance, the spot where the string is to be attached may, for the purpose of starting with some rough approximation to its proper whereabouts, be taken to be a little above the middle of a straight line drawn from shoulder to shoulder of the kite across its chest. If the kite be now suspended from the string, it will, or at any rate should, hang evenly balanced in

respect of its two sides, but with its head a little higher than the tail of its backbone. Presently, when cricket bats come under examination, it will be necessary to revert for a moment to this question of the place where the string should join the kite, and it will be convenient to adjourn what little remains to be said upon the subject to that occasion.

Before quitting, however, the general subject of kites, it may interest those to whom the information may be new to hear that the services of these toys were enlisted by the American philosopher Franklin in determining the real nature of lightning, which had not been understood until elucidated by his experiments. By flying a kite, and manœuvring it into a thundercloud, he tapped, as it were, the sky, and ran off its charge of lightning down the string into a receptacle where the electric fluid could be subjected to analysis. The string thus became an embryo conductor and electric telegraph also. The result of the experiments was to establish the fact, which had never been previously verified, of the identity of lightning with the electricity which may be generated by a machine.

In the old heathen mythology Prometheus is represented as stealing a spark from Heaven and bringing it to Earth, when Jupiter, like a late Chancellor of the Exchequer with his intended tax upon matches, had sought to deprive mortals of the benefits of fire. The modern Prometheus, Franklin, who not only stole thunderbolts, but showed that they were of a material by no means exclusively celestial, but were such as anybody could manufacture with some simple tackle of glass and silk, would have fared even worse than his prototype did,

according to the classical legend, if he had lived in mythological times, but Jupiter's day was over before America was discovered.

It was intimated just now that a kite and a cricket bat, though they might be supposed to be unlikely to have anything in common, present a point for consideration which occurs in both. If a cricket ball, or any hard, or resisting, object, be struck by the extreme end of a bat, everybody knows by experience the odious jar which a blow so given creates, sending as it does a painful shudder, like a shock from a galvanic battery, up to the elbow. The same sort of "unpleasancy" (to adopt a word from the vulgar tongue) occurs if the ball meets the bat just below the handle. Stinging sensations of the kind which has been described are familiar to anyone who has ever used a hoopstick. A sword, which would readily cleave an object meeting its edge at or near one particular point in its length, might be probably itself shivered, yet without accomplishing its intended task, if set to make a cut with a part of the blade close to either of its extremities. A knock given by mischance by the neck instead of by the head of a hammer might go far towards breaking the handle, but would be almost altogether devoid of effect upon the nail.

On the other hand, there is one exact point, and one only, situated, roughly speaking, at about three quarters of the way from the handle to the other end of a bat, hoopstick, or sword, or, in the case of a hammer, in its head, at which the striking implement, to achieve the best effect which it is capable of producing, should deliver its blow. This point is called

“the centre of percussion,” and the instrument which gives the blow will therefore be conveniently denominated as “the percutient body.” The centre of percussion is that spot at which the whole momentum of the percutient body is, as it were, concentrated.

The question why it is that a bat, or sword, or other percutient body, does its most efficient work under certain very precise conditions, only, which are easily ascertainable, and that a kite also flies its best when, and only when, the string is attached to it at a spot which is in fact its centre of percussion, is an interesting enquiry, and one of no great difficulty. To discuss it properly, however, at this moment would take too much time, so that it must be remitted to the category of matters which are suggested to you as worth examination at your leisure. To get hold of the matter properly, it will be necessary, as you will perceive, to consider the several different modes in which a percutient body may move, and what would be its centre of percussion in each case. It will be found that the centre of percussion must shift its place with every change in the manner in which the percutient instrument strikes. The centre of percussion, for example, of an object flying freely in any direction through space, and having a movement purely of translation and altogether exclusive of revolution, would be found to be necessarily in the line in which its centre of gravity is travelling. This would be the case with a bar of iron of uniform thickness and weight throughout its whole length, and projected through the air in the manner just described. If the same bar were to swing from one of its ends, as from a hinge, or other

fixed point of attachment, its centre of percussion would be found to fall between the middle of its length and its free extremity. The centre of percussion would thus be further from the axis of movement than the centre of gravity, which latter must obviously be half way along the bar.

Compound motions like those of a bat, a hoop-stick, or a sword, which are a combination of such as have been mentioned, bring the centre of percussion to some spot which is determined by the precise conditions under which the action of the percutient instrument takes place, that is to say by the manner in which it is wielded, whether with a sweep or hammer-fashion, and by the situation on its length of the place where it is held, or whence it is swung.

The centre of percussion of any instrument, say, of a rod when swung from one of its ends, may be roughly found as follows. Suspend it from either of its extremities by a string, so that it hangs vertically. If it be now struck with a stick at, or near, its top, the lower end will jerk towards the quarter whence the blow comes. If it be struck at or in the vicinity of its bottom, the top, in its turn, will, as it were, bow towards the source of the stroke. An intermediate point will readily be found by experiment whereat a blow will tend to drive the whole rod, including both its ends, altogether and unequivocally in the direction of the force applied. That point is the centre of percussion of the rod under existing circumstances.



CHAPTER XII.

THE reference which has been made to a hoopstick naturally brings to mind the other member of the partnership to which it belongs, to wit, the hoop. Some of the riddles which a hoop, with all its delusive appearance of extreme simplicity of behaviour, as well as of person, offers for solution cannot be expounded without the aid of clues which only a good mathematician would be competent to follow. A few moments' attention, however, may be bestowed on the main feature of its whole duty and conduct in its simplest form, namely that of rolling. The exact method by which this is produced will be best understood if we revert in the first instance to a top, and point out with some particularity of detail how entirely the agencies which are concerned with its spinning differ from those to which the revolving of a top is due. To revert to a top would seem to imply that an omission had been made when that toy was under review, but the one particular point of the manner in which its spinning is generated was advisedly reserved till this moment.

A top, as everybody knows, is most commonly set

going by means of a string which is wound round its spindle, and then pulled. Many other means may be, and often are, employed for the same purpose. Whipping tops are lashed; Japanese tops are mostly spun, like teetotums, by the fingers or by the palms of the operator's hands, while peg tops have the portions of their persons which are below their waists swathed by a coil of string. It will suffice, however, to consider the single case of a top spun by the employment of a string, as ordinarily done, not only because this is the most typical method, but because this may be taken and treated as being virtually the same as all and each of the plans, whatever they may be, which are adopted in other instances. For the same reasoning which will disclose the effect of the action of the string will be appropriate, with such slight modification, only, as may be called for by a difference in the form of the tackle used in any given case, to all the means by which tops are spun, every sort of appliance for this purpose, whatever it may be, doing its work on the same mechanical principle.

Suppose the string to be coiled round the spindle of the top, and thus to be ready for action. I do not know whether spindle or axle is the more proper term, but as we used axle just now we may take spindle for a change. When the operator pulls, he, in fact, as a little consideration will show, virtually produces action on the arm of a lever, one extremity of which is at the axis of the top, and the other, that, namely, to which force is applied, at the point where the free portion of the string meets the surface of the spindle.

In estimating the mechanical conditions of the state

of affairs which is thus constituted, attention may, of course, be confined to the field of action of the string, disregarding all the rest of the top, which is merely set in motion through its union with the particular part round which the coil is wound. Since, therefore, all the body of the top which is not directly operated on by the string may be left out of account as completely as if it had been cut away, it may, without introducing any source of error, be conceived to be actually removed. There will then be left for examination a section of the spindle as broad as, but no broader than, the coil of string. This may be again still further reduced, as far as the purposes of the problem which is before us are concerned, by discarding all but a mere bar joining the point of meeting of the string and spindle with the centre of the latter. This bar is to be supposed to be rigidly stiff, as is in fact mechanically true of it, so that, although infinitely slender, it will not bend. A pull from the string, which, as will be seen, cannot be given otherwise than virtually at right angles to the bar, twists the latter a little round the centre of the spindle, which is thus an axis of revolution. A very small and momentary compliance with the leading of the string terminates the whole relation between the bar and the external force. The string, uncoiling as it does, and coming off the disc along a straight line, immediately parts company with the end of the bar, since the latter obviously cannot move otherwise than in a circle, after a movement of revolution has been once set up. But the bar, being stiff, has acted as the handle of a windlass would do if similarly moved, turning the spindle of which it is a part a little round.

Now imagine a series of bars all, respectively, attached by one of their extremities to a common centre, and spreading thence outwards, like rays from a source of light, over a circular surface, thus forming a wheel. And suppose an arrangement to be contrived by which a string will exercise a continuing pull at one particular point of the outside rim of this circular area, then the end of each bar in turn, as the wheel revolves, will be subjected to the action of this force at the spot in question. If the bars were so numerous and closely packed as actually to touch, they would form a disc, which is what in fact we have to deal with, and the contrivance for making the pull of the string a continuous one is also present in the coil. The spinning of a top is thus seen to be caused by means of a sustained action upon the ends of innumerable bars which are, practically speaking, levers, and which are worked in rapid succession. The whole influence of this action is exclusively confined to turning the levers round, and it has no tendency whatever to transfer the disc which they may be viewed as composing to any other than its actual situation. The axis of the disc thus remains in one fixed position.

In a hoop, the movement of revolution is produced by mechanical conditions of quite a different kind. Suppose the hoop to be standing stock still, but ready for a start, and therefore maintained in an upright posture by the hand of its proprietor. When it is to be set going, it receives a blow, which, as will be remembered, will be delivered to the best advantage if it comes from the centre of percussion of the hoop-stick. If the hoop were floating freely in air or water, so as

to be wholly surrendered to the full effect of any propulsion which it might receive, without distortion of the result by the intervention of any fresh agent, the point at which a blow would have to be administered, to produce the greatest degree of movement of translation which its force could generate, would be readily ascertained. For, from what has been said, it is clear that it would be situated in the straight line representing the direction of the impulse, and passing through the centre of gravity of the hoop. Now, the course of the hoop, since it must take place along the surface of the ground, which we will assume to be flat, will be of necessity horizontal.

Suppose, then, a blow to be given, whose direction is horizontal and such as would also pass through the centre of gravity of the hoop, i. e. through the centre of the circle formed by the rim. The point of impact of a blow thus aimed will obviously be just half way up the rear side of the hoop. The tendency of a blow like this is simply to convey the whole hoop, bodily, in its existing attitude, but without any movement of revolution, along the straight line in which the impulse which has been generated acts. But directly the hoop begins to move, another force comes into play, namely, that of friction, which is generated by the rub against the ground of the particular portion of the rolling ring which is, for the moment, in contact with it. The action of friction must, from its nature, always take place in a direction exactly opposite to that of the motion of which it is the consequence. It is, in fact, reaction, which, as you already know, is always exactly contrary to action. Thus its

effect in the instance which is before us is to resist the passage of the lowest portion, for the time being, of the hoop along the surface of the ground. Were the motion of the upper part of the hoop similarly opposed, and to an equal degree, no propensity to revolution would arise, but since the upper surface is free to follow the impulse by which it has been animated, its progressive tendency, as will readily be seen, is such as to turn it over the retarded point of the circumference of the hoop as though round a fixed axis. The two sides are manifestly neutral in the adjustment of the balance of the forces by which rotation is determined, so that the hoop may be considered as wholly surrendered to the control of the pair of agencies which have been noticed, and the natural consequence must be such as has been pointed out. One distinction which there is between the spinning of a top and that of a hoop has now become plain, and it is this, namely, that in the former case the axis of revolution is stationary, and that in the latter it has a progressive motion.

A sentence or two at this place on the subject of friction may not be ill bestowed, since it is a force which, as we surmise, pervades Creation generally, toys and the rest of the Universe included, and we have continually had occasion to refer to it. It causes, as we know, the rolling, and is active in the stopping, of every child's hoop that is ever trundled, but it concerns itself with larger matters, since it strives to arrest the progress of whatever moves, if rubbing against anything on the road is an incident to the process of accomplishing a change of place. Water, for example, running through a pipe, moves more slowly at the

outside than at the middle of the current, owing to the friction of the liquid against the interior surface of the channel.

The theory is largely entertained, although not universally accepted, that the expanse of the Heavens is filled with ether of extreme tenuity, so that friction acquires some power of acting on all the bodies which traverse space, since they have to part this thin vapour or medium, or whatever it may be called, in their flight. The fact which has been noticed, and well verified, that certain comets do not reappear so soon as they should, and would do, were not their proper speed, as calculated in their known orbits, retarded by some agency or other, is, rightly or wrongly, taken as evidence, no other explanation of this anomaly in their conduct being at present forthcoming, that they have to cleave an attenuated atmosphere of some kind or other. This Ether, as is surmised, by the coherence of its particles, or by their inertia, that is to say, by their indisposition to be jostled aside, causes friction, whereby a sensible reduction of the comet's speed is brought about. If this be really so, the Earth, although it is not, like a comet, a mere glittering film of silvery haze, yet it must none the less, in the fulness of time, when its speed of revolution in its orbit, and the consequent centrifugal force, have both together been gradually undermined by friction, be carried into the Sun. For the attraction of gravity which will have been less and less kept in check, will then be absolute master of the situation. At this goal of our course we shall have been preceded, no doubt, by many comets, which, like moths flitting in lessening circles round a

flame, and eventually immolating themselves in it, will have already hurried to destruction.

Friction has been spoken of as the direct opponent to motion. In some respects it is so, but notwithstanding that general tendency, it is in many cases indispensable to the accomplishment of progress. In the instance of railway carriages travelling along smooth rails there is much less friction than is excited by vehicles on an ordinary road, the diminution of the force which is antagonistic to progress having been the very reason for the adoption of the metals. Consequently, a train is far more readily drawn on rails than it would be on a highway. But the train cannot be started or kept going without the aid of friction, for it is this alone which causes the driving-wheel of the engine to bite the metal and thus itself roll forwards, dragging the carriages after it. Were friction absent, this wheel would spin fruitlessly in one spot, as, indeed, we often see it do for a moment or so at the starting of a very heavy train when its power to grip is overborne by the strain caused by the inertia of the load which is to be moved.

Similarly, in the case of a cart and horse, friction is an indispensable condition of progress. Smoothness of the road means, no doubt, a mitigation of the resistance which the horse has to overcome in drawing the vehicle. But it also means a diminution of the friction between his shoes and the surface of the road, that is to say in other words an impairment of the effectiveness of his foothold. Therefore, when friction is reduced to a disadvantageous extent, as in the case of a road coated with ice, progress becomes pro-

portionately difficult to accomplish. It is friction which enables us to walk, and it need scarcely be added that a walking-stick would be useless in the absence of this force, since its lower end, slipping unrestrainedly as it would then do, could acquire no fixed point of support on the ground. Propulsion therefore would not be obtainable, since there would be no resistance against which to thrust, nor, without friction, could the other end of the stick be retained in the grasp of the pedestrian.

The force of which we have been speaking is not, like gravitation, a mysterious power of which we can give no further account than that it exists, and that its operation may be watched and measured. It is simply cohesion resisting motion, and is not, therefore, strictly speaking, a force at all. It has no tendency to generate motion, which is the main essential characteristic of a force. Its nature may be described as follows. Suppose that you have a very smooth surface such as that of a looking-glass, or an even yet more sleek-faced object, such as one of the Whitworth planes which were alluded to just now, however carefully it may have been polished down towards a condition of extreme flatness, there still always must and will occur in it tiny prominences and depressions; in fact it will be a hilly plain, and will stand revealed as such when closely examined under a microscope. Now suppose another surface of a like character to be made to slide over this. This second surface, however level to the eye, will, in reality, be similarly rugged, and consequently, when the two are in contact, and when there is motion either on the part of one only, or on

the part of both, but not precisely at the same rate, and in the same direction, there must ensue a process of bumping of the tiny mountains which emboss the one against those which pimple the other, as progress is made. Rub the faces of two nutmeg-graters together, and you will get a clear-cut illustration of what is meant.

Friction augments with any increase of the force which presses together two moving surfaces, because then the little asperities which have been spoken of, instead of sliding over one another with more or less difficulty, are forcibly brought to succumb to a violent process of mutual grinding, by means of which they are partially or completely levelled. The cohesion of their particles does, of course, its utmost to resist this demolition of their structure.

For the purpose of conveying a general notion of friction as a whole, it has been spoken of, advisedly, up to this point, as if it were a force whose origin and manifestations are always uniform. But this would be an inaccurate account, if it were to be put forward as altogether true in detail. Friction is of two kinds. One of these occurs in the case where it successfully resists the occurrence of any motion whatever. Take, for example, any object standing upon any table. No table or any other surface is (or at least the chances against its being so are infinitely great) exactly horizontal. If, therefore, it were absolutely smooth, and anything standing upon it were so also, the latter would of necessity certainly behave like a ball placed upon an inclined plane, and slide downwards towards the lowest situation which it could reach. Things

placed upon a table remain stationary in consequence of friction: that is to say, the roughness of the surfaces which are in contact quells all impulses towards motion before they can generate any effect whatever. The tiny eminences are, as it were, interlocked. Now when friction thus maintains rest it is usually called in the language of mechanics "statical friction." If by the application of some external force, as, for example, by a push, you cause the object which has been hitherto stationary to travel along the surface of the table, friction, or rubbing, of another, and more active kind, is called into being which is termed "dynamical." It is self-evident that an account might be given of dynamical friction by saying that it represents the transference, or transformation, of some part, more or less as the case may be, according to circumstances, of the motion of a moving body. It is either shifted over to the particles of the medium, or surface, which environs or touches the line of march, producing among them a certain amount of dislocation of arrangement, or, if displacement be more or less successfully resisted by them, then motion to the same amount reappears as its *alter ego*—that is to say in its other phase of heat. The conditions on which the powers of statical and dynamical friction respectively depend are not quite the same. This matter is one which is recommended to you for consideration hereafter.

It will be now seen why no general rule, applicable to all circumstances alike, can be laid down by which the precise spot at which a hoop should be struck in order to produce the fullest effect of impulsion will be ascertainable. If the path along which the hoop is to

travel be very rough, that is to say if the obstacles with which it is beset be high and stiff, friction will be diminished if the blow from the stick be delivered low, so as to have, as it were, something of a lifting tendency, which will ease the transit of the projections over one another, and thus avoid evoking the obstinacy which would attend a more direct and uncompromising conflict. If, on the other hand, the course which is to be travelled be smooth, the higher will be the point which will be struck to the best advantage, provided, of course, that it be never above the horizontal line passing through the hoop's centre of gravity. For simplicity's sake, as you will remember, the hoop is supposed to journey on a flat path. The proper adjustment of traces with a view to economy of power in draught by horses will, of course, be prescribed by considerations some of which depend on friction.



CONCLUSION.

THE time which we have now spent among toys, although it has been long enough, perhaps, to exhaust your patience, has yet been insufficient for the complete discussion of any one of the subjects which have come under review. Supposing, therefore, as seems to be the case, that we have now glanced at most of the common playthings which first come to hand in an ordinary nursery or playroom, there is no occasion to beat further afield, so as to take in others whose claim to be regarded as toys is debateable, since any inexhausted capacity for attention with which you may be credited would be better employed in surveying once more the ground which we have traversed too hurriedly, rather than in prosecuting expeditions into fresh territory which we are not strictly called upon by the terms of our programme for this evening to explore. Otherwise, a tobacco pipe, whenever it is used for its best, although not its primary purpose, namely, that of blowing soap-bubbles, might be held to have a just title to take rank as a toy. Blowing bubbles may claim to bear some semblance of an historical, as well as other, interest. For it may be supposed that the idea of a balloon is due

to the suggestion offered by Nature through bubbles. Indeed, the first rudimentary project of lifting some kind of bag into the upper air by means of inflation with a fluid lighter than the atmosphere, took the form of blowing soap-bubbles full of gas. But to do our duty properly by a soap-bubble would take an indefinite quantity of time and pains. For it presents illustrations of the working of many of the laws of Nature which are of the widest application, of the most paramount importance in the arrangement of the Universe, and the main sources of order and beauty.

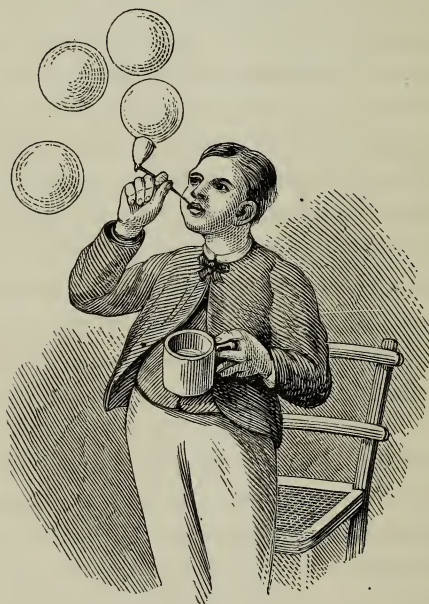
For example, on sitting down with a pipe and a basin of soapsuds preparatory to commencing operations in bubble-blowing, it would be impossible to help noticing that most, but not quite all, of the separate little chambers of which any mass of the foam which is before us is composed are hexagonal, that is to say, six-sided. There must be some cause for this. On learning how this arrangement is brought about, the reflection must immediately occur that the agency to which it is due must be at work all over the domains of Nature. Such is discovered to be the case, since its characteristic mark will be detected scored upon innumerable animal, vegetable, and mineral structures. On proceeding to blow bubbles, it is found that for some reason or other, although they may be elongated for a moment by a stiff blast into a grape-like form, they cannot be made to retain permanently, or even for a moment, with their own consent, any other shape than that of a round ball. An acquaintance with the law to which the bubbles so obediently and persistently conform reveals to us the origin of the figures of numberless things in nature,

among which is that of the globe on which we live. The same law is at the bottom of most of the mechanical work which is done in the world, whether it be such as Nature herself undertakes, or that which the hand of man accomplishes by the intervention of machines.

The lovely iridescent hues which adorn a bubble cannot fail to excite a curiosity which is not very easily gratified, since the department of the science of optics which treats of the origin of what are called "the colours of thin plates" is rather a difficult region of study. The coat of many colours which forms both the body and raiment of a bubble is of a finer texture than was ever turned out from the fairies' loom, since, according to Sir Isaac Newton who measured it, and who had a trick of being right, it is at its thinnest part not more than $\frac{1}{2,600,000}$ of an inch thick. I mention these facts merely, if possible, to excite interest and stimulate inquiry by showing that as there are, as we know, "sermons in stones," so, also, there are teachings in toys which are worth eliciting.

The road to an elementary knowledge of common things may seem a little harsh at the outset to the unpractised tread, but those who find this to be so may take heart of grace through the confident assurance that the path will soon become one of pleasantness. On the wall of a dungeon in the Tower there is an inscription, carved, as its tone and import would seem to indicate, by some poor doomed prisoner, condemned to death, and equipping himself with calmness for his last journey. It runs thus: "Par passage pénible passons à fort plaisant." The seriousness, if not pathos, which these few words seem to condense impressed me, when I first

read them, on being taken, as a boy, to see the Tower. They apply with truthful and grave force to such efforts as any of us can muster the courage and spirit to make for our own improvement.



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